3 Research and Development

Under our Research and Development (R&D) activities, BT will conduct a balanced portfolio of high-risk and applied research to accelerate the introduction of energy efficient building technologies and practices.

Research is conducted in two areas: systems integration; and from that analysis, component R&D. Systems integration research and development activities analyze building components and systems and integrate them so that the overall building performance is greater than the sum of its parts, often using the components developed by BT. In turn, research and development of individual building components (envelope and equipment/appliances) provides the technical basis for significant contributions to achieving net-zero energy performance in buildings.

Building system integration is analogous to the process used in the production of airplanes and automobiles. Using a systems approach will result in higher performance throughout the building life cycle: site selection, design, construction, commissioning, operation and maintenance, renovation, demolition, and replacement.

In many end uses, new, advanced component technologies could be twice as efficient as conventional components and still meet the challenging reliability and cost requirements in buildings. Used in retrofit application, these technologies provide one of the best opportunities to increase energy efficiency in existing buildings. These buildings will dominate energy consumption in the building sector for the next several decades.

Through BT's multi-year planning process during the winter of 2005, key priorities were developed for selection of the portfolio of activities. These priorities are (in order of importance):

1. Research and development to create systems integration solutions to enhance the technical energy efficiency of whole residential and commercial building new construction (including substantially new commercial construction) leading to marketable ZEH in 2020 and commercial ZEB in 2025.

2. Research and development to create technical solutions to component and equipment advancement needs identified through system integration research activities conducted in support of priority 1.

3. Research and development activities of an enabling nature (including simulation software and design guides) that enhance and support the activities conducted in support of priorities 1 and 2.

4. Research and development in systems integration, components and practices that when implemented primarily improve the technical efficiency of existing homes or commercial buildings through equipment replacement or retrofit

The development of technical targets with the Research and Development activities includes both top down and bottom up approaches:

- The top down approach - from the integrated whole building perspective - establishes a component by component cost-performance need to get to an optimized economic and performance result.

- The bottom up approach - from the component perspective - informs the top-down perspective by establishing the baseline (standard current practice), best current available, projected improvement and max potential performance of components.

Reconciling the two approaches yields the identification of gaps between the top down needs and the bottom up technologies and potentials, and also identifies the "good enough" states for the components in the optimized whole buildings context.

The individual component programs of Research and Development identify a time-specific target for providing the cost-performance solutions identified in the integration activities (residential and commercial). Further, the component research programs identify the maximum technical potential as an exit criteria at some point past the target associated with satisfying the whole building need, only if a strong enough justification for going beyond the optimized need can be made.

Setting component targets in excess of the identified needs is prudent given the uncertainty that each and every component would exactly meet the stated need and thus higher performance component research goals would allow room for trade-offs and flexibility in meeting the intent of the goal of ZEB.

Each section below describes the priority area of activity for BT Research and Development.

3.1 Residential Integration

The Residential Integration subprogram, Building America, focuses on improving the efficiency of the approximately 1.6 million new homes built each year.[1] These improvements are accomplished through research, development, demonstrations, and technology transfer of system-based strategies. The system-based strategies improve the energy efficiency through integrating residential energy uses, such as space heating and cooling, ventilation, water heating, lighting, and home appliances. These activities support efforts to develop strategies to integrate solar energy applications and other renewable technologies into buildings, and the concept for net-zero energy homes. Outputs from the subprogram include technology package research reports, which represent research results achieving a level of performance, and derived from these are Best Practices manuals, tailored for specific climate regions.

Table 3-1 Residential Integration Summary

Start date	1995
Target market(s)	New, Single-Family Residential Buildings
Accomplishments to date	1. Developing the Building America Benchmark Definition 2. Developing Protocols for Validating Whole House Energy Tools 3. Documenting Research and Publishing Houses That Work, Builder Guides, and Best Practices Manuals

[1] National Association of Home Builders, *Annual Housing Starts (1978-2004)*, 2004.

	4. Increasing the Number of Energy Star Homes
Current activities	2005 activities: Developing integrated cost-effective, whole-building strategies to enable new, single-family residential buildings to use 30% less total energy than the Building America Benchmark in the Cold and Hot/Mixed Dry climate regions.
Future directions	Continuing to develop the strategies for new, single-family residential buildings to use 40-100% less energy than the Building America Benchmark in the Marine, Hot Humid, Hot/Mixed Dry, Mixed Humid, and Cold climate regions
Projected end date(s)	2025
Expected technology commercialization dates	See Table 3-3 Residential Integration Performance Goals17F

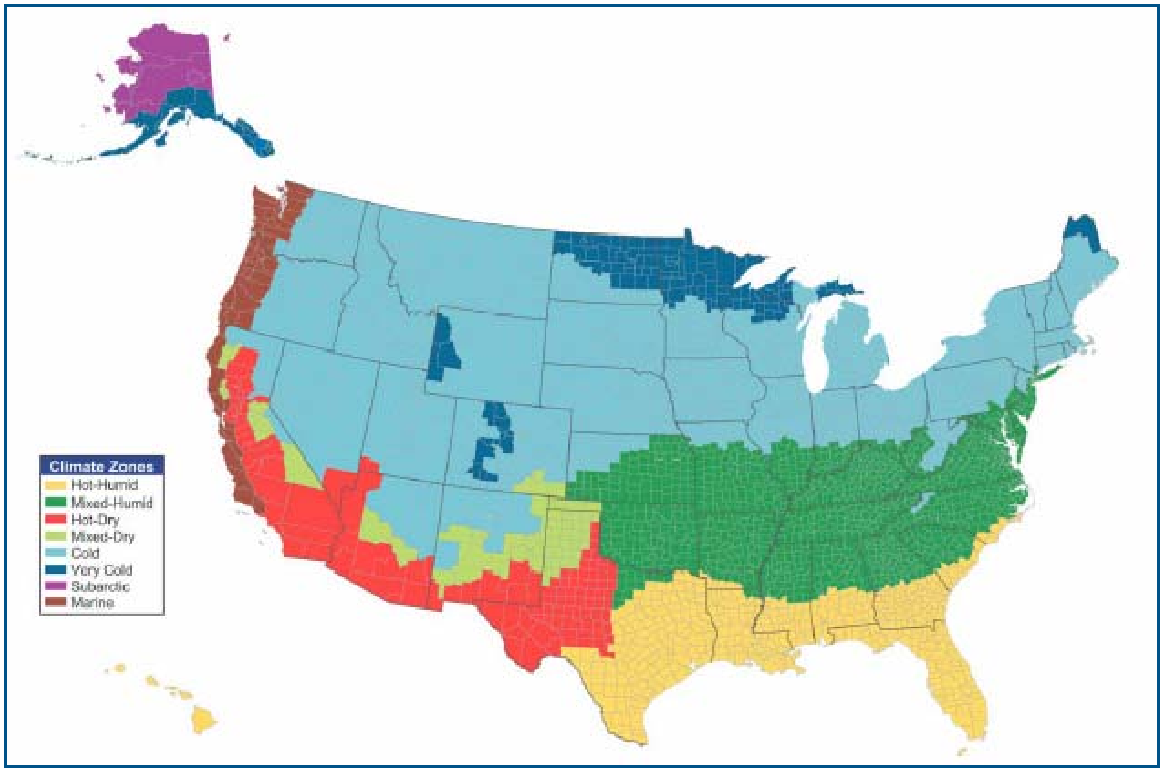
3.1.1 External Assessment and Residential Integration Market Overview

The residential market is the largest user of energy for buildings. It represents 52.5% of the total energy used by buildings, accounting for 21.8 quads in 2005.[2] New homes offer larger energy savings for less money than existing homes. The Residential Integration subprogram, or Building America, is targeting single-family homes because they are the single most important home sector from an energy use and growth in energy use perspective. Single-family homes currently consume 80.1% of the energy used for residential buildings, while multi-family and mobile homes use 19.9%.[3] Not only do single-family homes account for four-fifths of the residential energy use, but also over the next decade the single-family sector is projected to grow and account for over 70% of new housing units. Multi-family and manufactured homes will account for only about 30% of new housing units.[4] Due to resource constraints, Building America has chosen to focus on succeeding first in the single-family home market. Technologies developed for single-family homes can often be applied to multi-family homes.

Building America is targeting new single-family homes in six climate regions. Unlike other building types, residential buildings include a limited number of different end uses with many similarities in a particular climate region. Therefore, a climate region approach is appropriate because residential system solutions can be easily replicated on a regional basis. The climate regions defined by Building America can be seen in Figure 3-1.

[2] *2005 Building Energy Data Book*, U.S. Department of Energy, Office of Planning, Budget Formulation and Analysis, Energy Efficency and Renewable Energy. Prepared by D&R International, Ltd., August 2005. Hereafter, BED.
[3] BED
[4] Berson, David, et al, *America's Home Forecast: The Next Decade for Housing and Mortgage Finance*, 2004, Homeownership Alliance.

Figure 3-1 Building America Climate Regions[5]



Due to limited resources, Building America is targeting six of the eight climate regions, including Marine, Hot Humid, Hot Dry/Mixed Dry, Mixed Humid, and Cold. The Hot Dry and Mixed Dry climates have been combined into a single climate target for Building America planning purposes because of the similarities of the solutions for the two climates. The Severe Cold and Subartic climate regions have been omitted due to limited resources and the lack of residential growth in these regions.

There are two political nuances, the Partnership for Home Energy Efficiency (PHEE) and the proposed tax credit. The PHEE initiative is directed towards existing housing but there is currently no extra funding for this initiative. The Building America project will support the initiative by applying new home research solutions to existing homes. However, this will require some funding that could impact progress toward the net-zero energy house goal. The proposed tax credit should ultimately provide impetus toward more energy efficient housing, but in the short term could require some funding to develop any congressionally directed certification procedures.

There are no competing technologies since the Building America project relies on a systems integration or whole house approach. The other option would be to not do a

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[5] Anderson, Ren, et all, *Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes*, November 2004, National Renewable Energy Laboratory. Report No. TP-550-36920.

systematic integration, but rather take a component-based approach. The component-based approach does not account for the synergisms among subsystems, such as the use of more insulation, a low cost measure, so that more expensive air conditioning and heating systems can be reduced in size.

3.1.2 Internal Assessment and Residential Integration History

The Residential Integration subprogram, Building America, started in 1995 to conduct the systems research required to implement residential energy efficiency solutions that achieve 30-100% savings on a production basis. The long term 2020 research goal for the program is to develop cost effective system designs that can result in ZEH.[6]

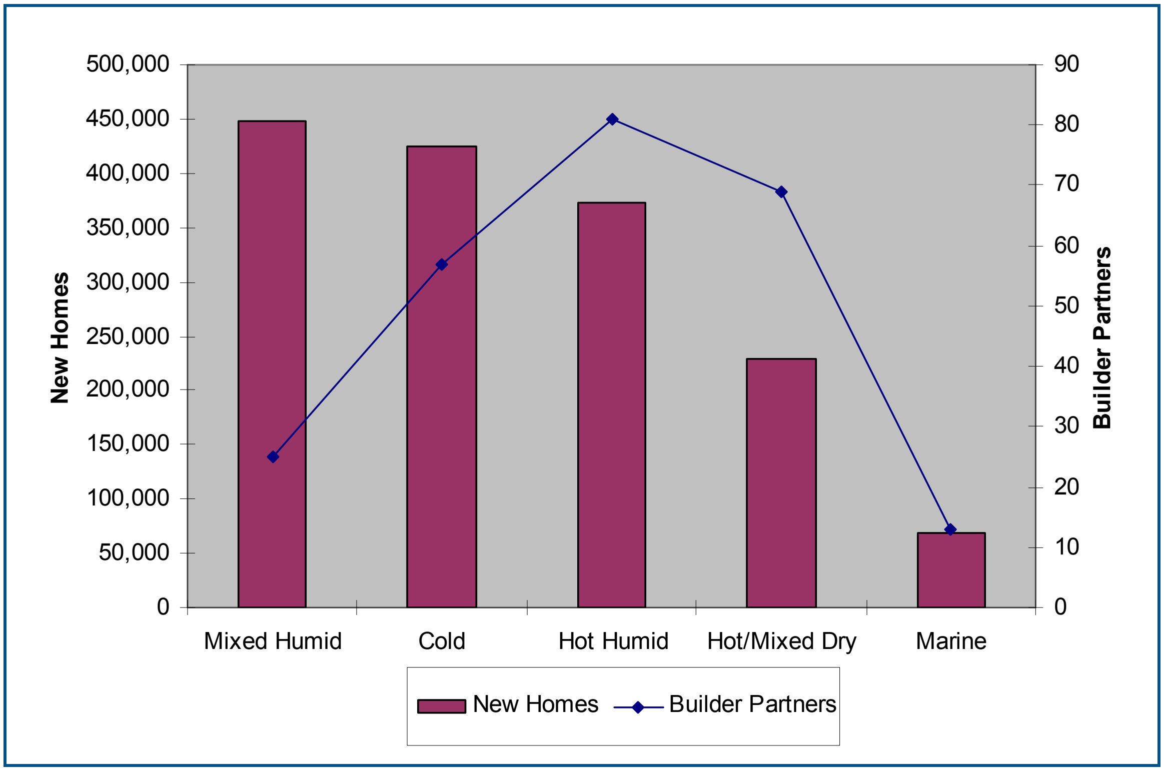
In the last ten years, Building America has completed several milestones on the path to ZEH. Building America has defined the benchmark for measuring whole house energy savings. In addition, the program has assisted RESNET in developing the protocols for validating whole house energy tools. Research has been documented and published, including Houses that Work, Builder Guides, and Best Practices manuals. Building America's efforts have also helped increase the number of Energy Star Homes built, surpassing the forecast.

Building America is currently focusing on developing solutions to use 30% less whole house energy than the Building America Benchmark for the Hot/Mixed Dry and the Cold climate regions. These climate regions present opportunity for research due to the number of new homes being built and the relationships established with builder partners. The number of new homes and builder partners for each climate region can be seen in Figure 3-2. Building America will focus on developing the 30% solutions for the Mixed Humid and Marine regions in 2006.

Through 2020, Building America will continue to develop the strategies for new, single-family residential buildings to use 30-100% less total energy in the Marine, Hot Humid, Hot/Mixed Dry, Mixed Humid, and Cold climate regions over the full range of house sizes, styles and price points.

[6] A net-zero energy house produces as much energy as it uses on an annual basis through appropriate integration of energy efficiency solutions and onsite power systems with average occupant energy profiles.

Figure 3-2 New Homes [7] and Builder Partners[8] by Climate Region



A recent study by the RAND Corporation for HUD's Partnership for Advancing Technology in Housing (PATH) entitled, *Building Better Homes: Government Strategies for Promoting Innovation in Housing*[9], concludes that,

> "… The housing industry is large and complex, involving many public and private entities. The interests, roles, and capacities of each participant and the relationships they share have shaped the housing industry into what it is today…Instead of trying to identify barriers and asking the industry to change itself (or asking the government to change it), this study seeks to identify options to accelerate innovation within the housing industry as it exists today. It begins by critically examining the concept of innovation and how it might be better understood within the context of the housing industry. What results is a departure from the linear model of innovation that assumes logical and unidirectional movement from research to development, demonstration, and deployment to one that recognizes much

[7] U.S. Census Bureau, *Annual Estimates of Housing Units for Counties: April 1, 2000 to July 1, 2004,* Last revised September 2, 2004.

[8] U.S. Department of Energy – Building Technologies Program, *Building America: Project Locations,* Last revised February 3, 2004.

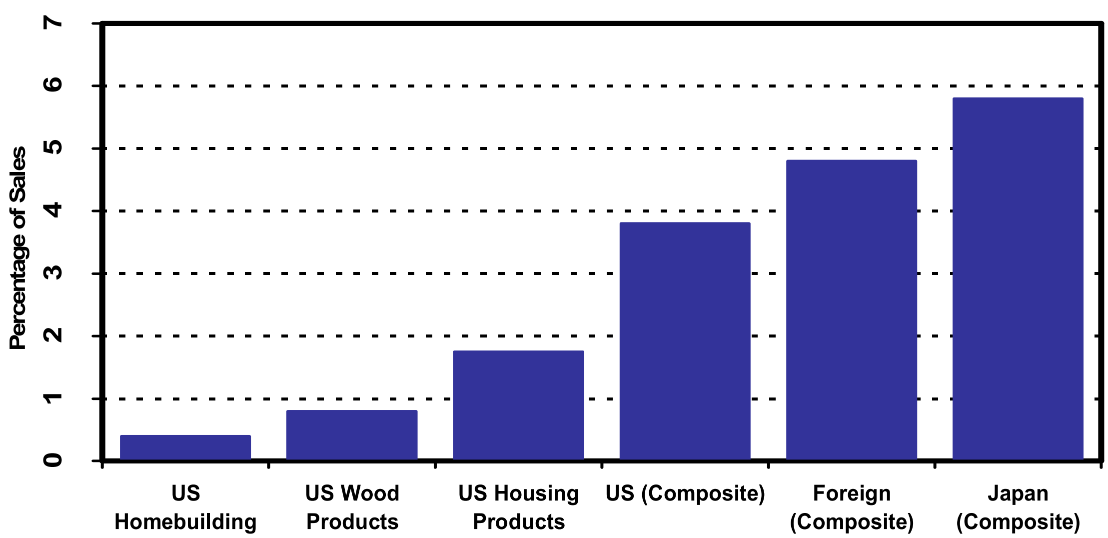
[9] *Building Better Homes: Government Strategies for Promoting Innovation in Housing,* U.S. Department of Housing and Urban Development, Office of Policy Development and Research and the Partnership for Advancing Technology in Housing. Prepared by Rand Corp., 2003.

greater interactive dynamics in the innovation process. Research in this model is a base for knowledge, which contributes to invention, development, demonstration, and deployment. Moreover, all these activities or stages in the innovation process are affected by market forces."

As RAND concluded, the housing industry has departed from the linear and deployment models of innovation and needs a model that accounts for the greater interactive dynamics in the innovation process. Therefore, a system-based research approach is needed that can provide valuable benefits to builders, consumers, and utilities while simultaneously resolving market and technical barriers to innovation.

The Federal government should conduct the residential integration systems research because the industry has little resources for research and is very risk intolerant. Figure 3-3 illustrates the housing industry's low level of investment in R&D relative to other sectors of the economy, less than one percent of sales. The U.S. homebuilding industry invests 0.25% of sales in research compared to 3.8% for all market sectors.

Figure 3-3 Research and Development Expenditures[10]



The Federal role is necessary yet complementary to the States because some research solutions for energy efficiency are similar across several climates and BT has the responsibility to improve the residential building codes. Some of the research approaches to energy efficiency, like unvented attics and crawlspaces, require waivers to current codes in order for them to be used. One of Building America's key activities is to move these into the building codes process so that new energy saving practices can be codified.

[10] Coy, Peter, et al, R&D Scoreboard: In the Labs, the Fight to Spend Less, Get More. *Business Week*, June 28, 1993.

DOE has already had success with the systems-based research approach as demonstrated by Pulte Homes, which,

> "… Has used technical assistance from the Department of Energy's Building America program to create what one residential expert calls "the best production house in the world," which won the 2001 National Association of Home Builders' Energy Value Award. In Tucson, Phoenix, and Las Vegas, Pulte Homes has worked with the Department of Energy to redesign the energy features of its basic models. Using advanced insulation techniques, highly efficient equipment and windows, and right-sized heating and cooling systems, the homes look the same, but perform so well they use half the energy for heating and cooling at virtually no increase in construction costs. The whole building/systems engineering approach used in the Building America program allows builders to add more insulation and more efficient windows while reducing the size of the heating and cooling equipment. The trade-off means no added cost to the builder, better value for the buyer, reduced electric load for the utility and improved affordability." (*National Energy Plan, p 4-7.)*

The Residential Integration subprogram complements the Solar program, HUD PATH and the EPA's Energy Star New Homes program. It does this because a significant part of the approach to ZEH will rely on the use of renewable energy, such as solar PV. We coordinate with HUD's PATH program and provide links to each other's websites so the public can find more information at one place. The Residential Integration project has clearly helped the Energy Star New Homes[11] program because it provides the research that demonstrates how to build energy efficient homes at no net increase in cost for the mortgage, i.e., the energy savings pay for the increased mortgage payment.

Townhomes built by Ryan Homes in partnership with the Consortium for Advanced Residential Buildings (CARB) as part of the U.S. Department of Energy's Building America Program.

3.1.3 Residential Integration Approach

Building America conducts a systems research approach for single-family homes in six climate regions to meet the stated goal of developing integrated energy efficiency and onsite/renewable power solutions to reduce whole-house energy use in new homes an average of 40% by 2010[12]. In order for energy efficient solutions to be viable candidates over conventional solutions, it must be demonstrated that they can cost-effectively increase overall product value

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[11] U.S. Environmental Protection Agency – Energy Star, *New Homes,* April 2004. Brochure No. EPA 430-F-03-023.

[12] 2010 target assumes level funding for Building America system research activities for 2006-2015.

and quality, while reducing energy use. Building America's systems research approach provides opportunities for cost and performance trade-offs that improve whole-building performance and value, while minimizing increases in overall building cost. Alternately, a component research approach would not account for system interactions, creating integration barriers and additional risk in meeting energy savings goals cost-effectively.

To meet the objective cost-effectively, Building America conducts systems research by combining operations research and systems engineering. The first step of the systems research is to use operations research techniques to identify the technology pathways that will achieve the target energy savings in each region for the lowest potential installed cost. From these results, the optimal efficiency targets can be identified and technologies can be developed that will meet the energy savings needs cost-effectively in all climate regions. The second step in the systems research is to implement the optimal technology pathways through systems engineering in homes. The systems engineering step will identify challenges and barriers unanticipated by the optimization. The combination of operations research and systems engineering will ensure that the solutions created will meet the energy savings and cost goals, and can be used on a production basis.

As part of the testing program, researchers test the energy efficiency of air ducts.

The systems research described above is applied in three phases for each climate zone. Building America acts as a national residential energy systems test bed where homes with different system options are designed, built and tested during the three phases, which are conducted in parallel to allow feedback between phases. Research houses, production prototype houses, and evaluations in community scale housing validate the reliability, cost effectiveness, and marketability of the energy systems, when integrated in production housing.

After completion of the community evaluations, a low level of technical support may be provided as needed to ensure successful implementation of system research results at each performance level targeted by the program. A detailed summary of the three phases of the system research process is captured in the strategy diagram below.

Figure 3-4 Residential Integration Systems Approach

Pre-Phase 1 Identification of Component Development Needs

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Phase 1 Systems Evaluations

In Phase 1, the Building America Consortia design, construct and test subsystems for whole house designs in research houses to evaluate how components perform. The focus of Phase 1 is to evaluate and field test prototype subsystems to determine the most reliable and cost effective solution for a given performance level and climate.

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Phase 2 Prototype Houses

In Phase 2, the successful Phase 1 subsystems are designed and constructed by production builders working with the Building America Consortia to evaluate the ability to implement the systems on a production basis. The focus of Phase 2 research is to move the research prototype house and building practices to the point that they are production-ready, capable of being integrated with production construction techniques practiced by today's builders.

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Phase 3 Community Evaluations

In Phase 3, the Building America Consortia provide technical support to builder partners to advance from the production prototypes to evaluation of production houses in a subdivision. The results are documented in a case study report. Several of these reports are distilled into a final research report that describes the system design and construction practices needed to achieve a particular level of energy savings within each climate zone targeted by the program.

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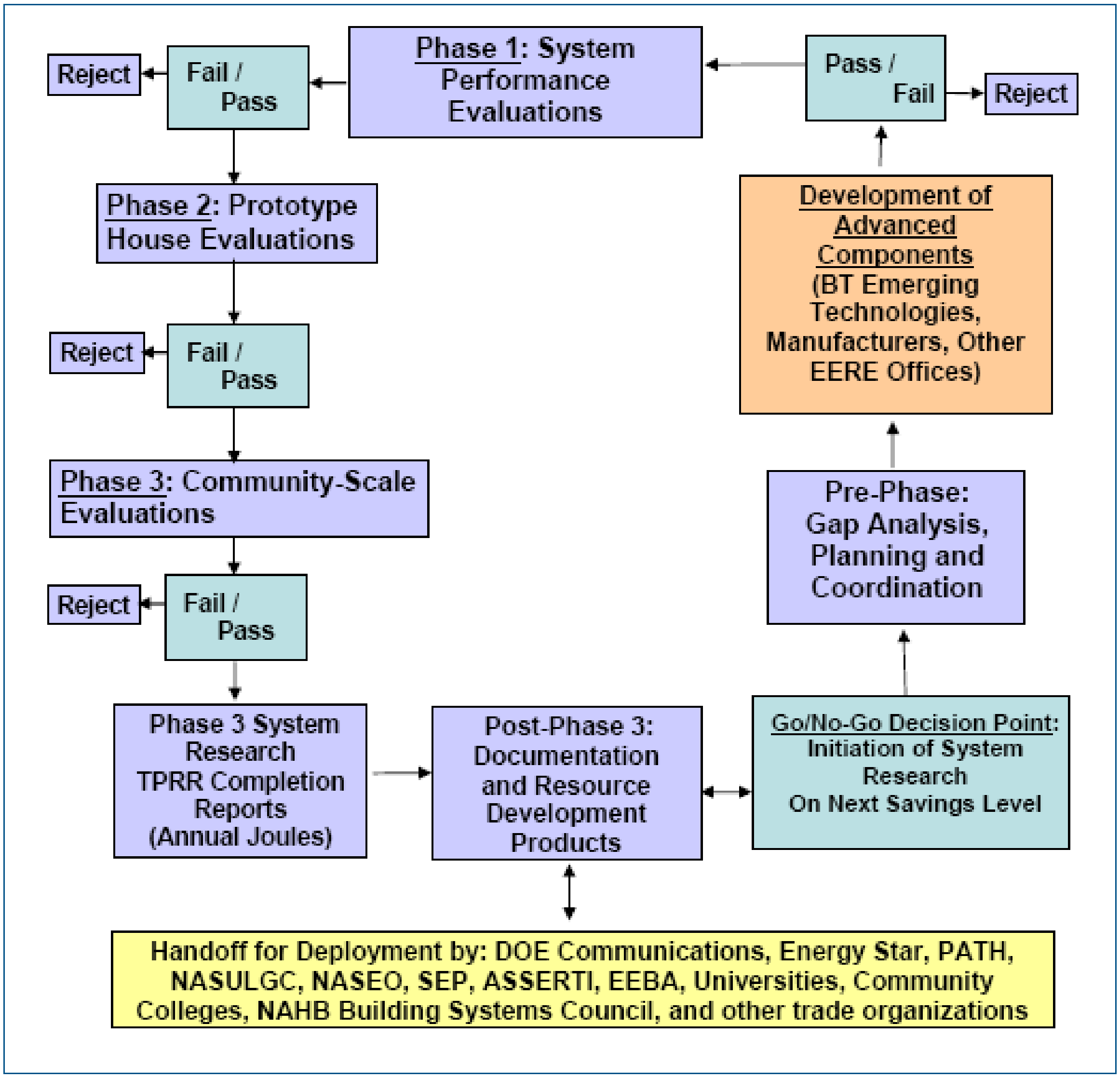
Post-Phase 3 Documentation and Resource Development

The three system engineering stages overlap one another to allow issues to be quickly resolved, as they are identified. The three system research stages currently take about 3 to 4 years per climate region, but for more advanced energy efficiency levels at and above 40% whole house savings, the system research process is expected to take additional iterations of whole house testing before implementation in production ready homes. At the 50% whole house level and above, the system research stages will probably take 4 to 5 years to complete for each climate region.

Figure 3-5 Residential Integration System Research Process



Electronic Reporting of System Research Results
Final research results from the program are reported electronically via the Building America Website (http://www.buildingamerica.gov). Research results include project data, research reports, case studies, research highlights, and background information on the research program and its participants. The website also includes a document database and reference materials on the performance analysis and measurement procedures.

Electronic Reporting of Project Plans and Research Progress
A password protected project management website is used to provide a central location to post project plans, monthly reports, deliverable reports, expert meeting reports, and milestone reports.

Identification of Component Development Needs
The three phase systems engineering approach requires identification of future system needs to allow the lead time required to develop and evaluate options to meet those needs. Prior to initiation of Phase 1 studies in research houses, components must be developed and evaluated to determine their potential to fill gaps between the performance of current systems and future whole house performance goals. These components are developed in collaboration with industry partners, the Emerging Technologies Program, and other EERE offices. The component research requires significant lead time in some cases and focuses on communication of system integration needs and requirements to component developers. Building America's role is to provide inputs to component developers that help to identify residential system integration needs, requirements and gaps based on annual residential cost/performance studies using the BEOpt analysis method.[13] Components must be developed for Phase 1 and have to meet minimum requirements for energy performance, reliability, and cost effectiveness before they are included as part of the residential integration activities in Phases 2 and 3.

Documentation and Resource Development
At the completion of phase three, the research results are documented in technical research reports that serve as references for students, educators, building scientists, architects, designers, and engineers. For the research results to be successfully transferred to additional important participants in the housing industry, they must be translated into a format appropriate for dissemination to developers, builders, contractors, homeowners, realtors, insurance companies, and mortgage providers.

This post-Phase 3 DOE activity fosters movement of the research and building techniques of Building America to the market, and establishes voluntary collaborations with housing and financial industries to make the nation's houses more energy-efficient and affordable. This final stage of the research process focuses on documentation of best practices manuals and development and evaluation of resources to hand-off DOE building research findings to private and public sector implementation programs. This work supports activities that improve the energy efficiency of public and privately owned single-family housing. The subprogram coordinates presentations at technical conferences on peer reviewed, validated, research results and facilitates validation, field-testing, and evaluation of the post-phase three documentation.

The Building America resource development effort creates "Best Practices" manuals from the Phase 3 research reports that are designed for builders, manufacturers, homeowners, realtors, educators, insurance companies, and mortgage providers. The Best Practices manuals summarize best practice recommendations in illustrated text that is targeted to a specific audience to make it easily assimilated, and that synthesize research findings into energy-efficient processes for the building industry. To facilitate construction of affordable homes designed for non-profit organizations and small

[13] Anderson, Ren, et all, *Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes*, November 2004, National Renewable Energy Laboratory. Report No. TP-550-36920.

builders, BT plans to make floor plans and section details available through the web and other means.

In addition, Building America will provide train-the-trainer course reference materials to be used by existing training programs throughout the building industry. We provide train-the-trainer reference materials in partnership with ongoing training programs sponsored by professional organizations, universities, community colleges, vocational schools and others involved in the education and training of those associated with the design and construction of homes. The current schedule for development of Best Practices manuals for Energy Star builders (the 15 percent whole house performance level) is shown in Table 3-2. The documents allow a handoff of DOE's building research findings to the private sector.

These post-Phase 3 efforts also document Building America's best practices and lessons learned in over 25,000 energy efficient new houses of all sizes, styles, and price points, constructed to date by Building America partners. Initial emphasis of the first Best Practices volume has documented practices for construction of energy efficient houses at the 15% savings level in the hot humid climate region and has illustrated the results through case studies. As Building America efficiency goals ratchet up between now and 2010, similar documentation packages will be developed for whole-house conservation and renewable energy generation levels of 30 to 40 percent. These materials, including the research reports, are all available on the web at http://www.buildingamerica.gov.

Table 3-2 Residential "Best Practices" Schedule

Target	Marine	Hot Humid	Hot/Mixed Dry	Mixed Humid	Cold
15%	2006	2004	2005	2005	2005
30%	2007	2008	2006	2007	2006
40%	2009	2011	2008	2009	2008
50%	2012	2016	2013	2014	2015

The systems research approach is the approach best suited to meet the stated goals because the three phases allow for the early identification of performance gaps and allow for reallocation of resources to other high-priority system research areas when required. Building America identifies and resolves the barriers through the series of design and test studies at each phase of development. By identifying inefficiencies early, Building America will create an efficient process for introduction of higher energy efficiency to production housing by Phase 3.

3.1.4 Residential Integration Strategic Goals

The Residential Integration subprogram will develop integrated energy efficiency and onsite/renewable power solutions that will be evaluated on a production basis in subdivisions to reduce whole-house energy use in new homes by an average[14] of 50% by 2015 and 90% by 2020 compared to the Building America Benchmark[15,16] at zero or less net cash flow.[17]

3.1.5 Residential Integration Performance Goals

Building America developed the following performance goals for each phase of the systems approach. The performance targets show the energy savings that will be reached on the path to net-zero energy homes.

Table 3-3 Residential Integration Performance Goals[18]

Characteristics	Units	Year				
		2007	2010	2015	2019	2020
Average Source Energy Savings	%	30	40	50	60	90
Cost	$	Zero or Less Net Cash Flow				

To ensure meeting the interim targets along the path to ZEH, Building America has also specified the following interim performance targets for each climate region below. These performance targets also serve as the annual Joule milestones for the program.

Table 3-4 Phase 3 Residential Integration Performance Targets by Climate Region

Target (Energy Savings)	Marine	Hot Humid	Hot/Mixed Dry	Mixed Humid	Cold
30%	2006	2007	2005	2006	2005
40%	2008	2010	2007	2008	2009
50%	2011	2015	2012	2013	2014

[14] The distinction between the average savings and the range of savings is important because it is not cost effective (or even possible without wasteful over engineering) to design a net-zero energy home for every possible potential occupant. Because the range of possible occupant behavior is large, the average savings target in 2025 is 90%. This average will include a significant number of homes that achieve 100% savings, ensuring that the goal of net zero energy homes is met.

[15] *Building America Research Benchmark Definition*, December 29, 2004, National Renewable Energy Laboratory.

[16] The Building America Research Benchmark Definition consists of the 2000 IECC envelope requirements plus lighting, appliances and plug load energy levels derived from best available research studies and energy use data for 1990's housing stock.

[17] Net cash flow is the monthly mortgage payment for energy options minus the monthly utility bill cost savings. "Zero or less net cash flow" means that monthly utility bill cost savings are greater than the monthly mortgage payment for energy options. In other words, the increase in a 30-year mortgage payment is offset by the energy savings.

[18] Year of completion of annual JOULE targets in six climate regions. Energy savings are measured relative to BA Research Benchmark. This schedule assumes that funding for Phase 1-3 system research activities will remain at FY 2005 levels.

The performance goals are aimed at achieving the strategic goal of ZEH by 2025. The performance targets are incremental, 30%-40%-50%, to manage research risks, closely track progress, and allow early identification and targeting of barriers to achieving the strategic goal of ZEH at zero or less net cash flow. Hence, the Building America system research strategy increases the performance targets leading toward long-term strategic goals based on the successful development of system solutions at the previous performance level.

Each of the performance goals is measured by comparing energy savings against the Building America Research Benchmark. The Building America Research Benchmark is based on the IECC 2000 and also includes lighting energy, appliance energy and plug loads. Progress can also be measured by the number of design packages developed, researched, and evaluated.

3.1.6 Residential Integration Market Challenges and Barriers

Construction of new homes requires the combined efforts of a large number of suppliers and contractors whose efforts are coordinated by a large number of builders. Because of the high costs of failure, the residential construction industry is highly risk-intolerant and first cost sensitive. Energy efficiency designs are further complicated by the development of new systems and the relatively low level of R&D investment. The key market barriers to development of advanced residential energy systems are the large number of market players, the relatively low level of investment in R&D relative to other sectors of the economy, and strict requirements for market acceptance based on achievement of low incremental costs and high reliability. The market barriers to meeting the Residential Integration strategic goal and performance goals are summarized in the following table.

Table 3-5 Residential Integration Market Challenges and Barriers

Barrier	Title	Description	Target
A	Identification of Cost Neutral System Solutions	Evaluation and validation of most cost effective options to achieve target energy savings	30-50%
B	Integration of Advanced Components	Identify performance gaps and advanced component cost/performance requirement	30-50%
C	Acceptance of New Building Practices by Industry Leaders	Evaluate new system options on a cost shared basis with lead builders, manufacturers and contractors	30-50%
D	Identification of Code Issues Limiting Adoption of Advanced Systems	Identify issues where additional performance information is required by local and national code officials to support broad use of advanced systems	30-50%

3.1.7 Residential Integration Technical (Non-Market) Challenges/Barriers

The key technical barriers to the development of advanced residential energy systems are the large number of technical performance requirements that must be met before a new system can be implemented on a production basis. These technical performance requirements are driven by regional differences in building energy loads and construction techniques. Systems that work well in cold climates may not be applicable in hot climates. Systems that work well in hot dry climates may not function well in hot humid climates. The technical barriers to meeting the Residential Integration strategic goal and performance goals are described in the following table.

Table 3-6 Residential Integration Technical Challenges/Barriers

Barrier	Title	Description	Target
E	Moisture Control	Vapor barrier, flashing, and drainage plane details required to ensure the durability of high R walls	30%-50%
F	Ventilation	Development of reliable energy efficient ventilation systems for high performance homes	30%-50%
G	High Performance DHW Systems	Reduction of distribution losses, integration of tankless hot water systems, and integration of simple, durable, low cost solar hot water systems	40%-50%
H	Contractor Ready Fluorescent Lighting Fixtures	Development of cheap and easy to install fluorescent lighting fixtures for all residential lighting needs	50%
I	Miscellaneous Electric Loads	Increase energy efficiency of miscellaneous electric uses and reduce standby losses	50%

3.1.8 Residential Integration Strategies for Overcoming Barriers/Challenges

The strategies to overcome market and technical barriers and challenges are described below.

Table 3-7 Residential Integration Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Integration of Efficient Technologies to Achieve Target Performance Level	Develop a systematic design and performance analysis method with integrated systems to lower cost and energy use
B	Integration of Advanced Technologies Into Standard Building Practices to Meet Cost Targets	Work with lead builders and contractors to accelerate adoption of advanced technologies and systems
C	Trade Acceptance of New Building Practices	Use an industry driven, cost shared, team-based system research approach to involve all participants in the residential construction industry in the development of new system solutions for high performance homes
D	Resolution of Code Issues that Limit Use of Advanced Systems	Provide research results and performance validation required to ensure broad acceptance of advanced systems by code officials
E	Moisture Control	Develop self drying high R walls
F	Ventilation	Provide outside air to homes with low cost mechanical systems; revise ASHRAE Standard 62.2
G	High Performance DHW Systems	Move water heaters and hot water distribution into conditioned space, reduce piping runs using smaller pipe diameter with thicker insulation, define hot water draw profiles required to evaluate and compare the performance of alternative system designs, improve part load performance of tankless hot water heaters, integrate low cost solar hot water systems
H	Lack of Contractor Ready Fluorescent Lighting Fixtures	Establish a volume purchase program to stimulate the development of quality, low-cost, fluorescent lighting fixtures
I	Miscellaneous Electric Loads	Reduce the energy used to meet plug loads and supplement with renewable technologies (Strategies TBD)

3.1.9 Residential Integration Tasks

The tasks that the Residential Integration subprogram will undertake to address each barrier and to meet the performance targets are described in the following tables. Table 3-8 describes the whole house tasks to overcome the market barriers.
Table 3-9 describes the component tasks involved in planning component program inputs into the residential system engineering research process.

Table 3-8 Residential Integration Whole House Tasks

Task	Title	Duration	Barriers
1	Phase 1 - System Evaluations: Design, Construction, and Evaluation of Prototype Systems that Meet Target Performance Levels	2 years	A. Integration of Energy Efficient Technologies to Achieve Target Performance Level
2	Phase 2 - Prototype Houses: Design and Build Prototype Houses Using Most Promising Systems from Phase 1 Evaluations	2 years	B. Integration of Advanced Technologies into Standard Building Practices to Meet Cost Targets
3	Phase 3 - Community Evaluations: Testing Production Ready Designs in Production Building Environment	2 years	C. Trade Acceptance of New Building Practices

Table 3-9 Residential System Component Needs

Component	Task	Title	Duration	Barriers
Envelope Materials	4	IRC Vapor Barrier Update	15 quarters	D. Resolution of Code Issues that Limit Use of Advanced Systems
	5	Self Drying High R Walls	25 quarters	E. Moisture Control
	6	Smart Insulation and Vapor Barriers	28 quarters	E. Moisture Control
Domestic Hot Water	7	Low Loss HW Distribution	10 quarters	G. High Performance DHW Systems
	8	90% Tankless Water Heater	12 quarters	G. High Performance DHW Systems
	9	Low Cost Solar DHW	26 quarters	G. High Performance DHW Systems
Lighting and Integrated Appliances	10	Contractor Ready Fluorescent Lighting Fixtures a. Residential CFL Fixtures b. T5 Fixtures c. T2 Fixtures	39 quarters	H. Lack of Contractor Ready Fluorescent Lighting Fixtures
	11	120 Lumens/W White LED	17 quarters	
	12	Miscellaneous Electric Loads Scoping Study a. 10% Misc. Electric Savings b. 20% Misc. Electric Savings c. 30% Misc. Electric Savings	31 quarters	I. Miscellaneous Electric Loads
Cold Climate Windows	13	R-4 Windows	12 quarters	
	14	R-10 Movable Insulation	12 quarters	
	15	R-10 Dynamic Super Window	13 quarters	

3.1.10 Residential Integration Milestones & Decision Points

The Residential Integration performance targets can be translated into a schedule for the three phase systems engineering approach. The figures below show the schedule for whole house and component tasks. The end of each task is the milestone and also where the go/no go decision occurs for the next phase.

Figure 3-6 Building America System Research Gantt Chart

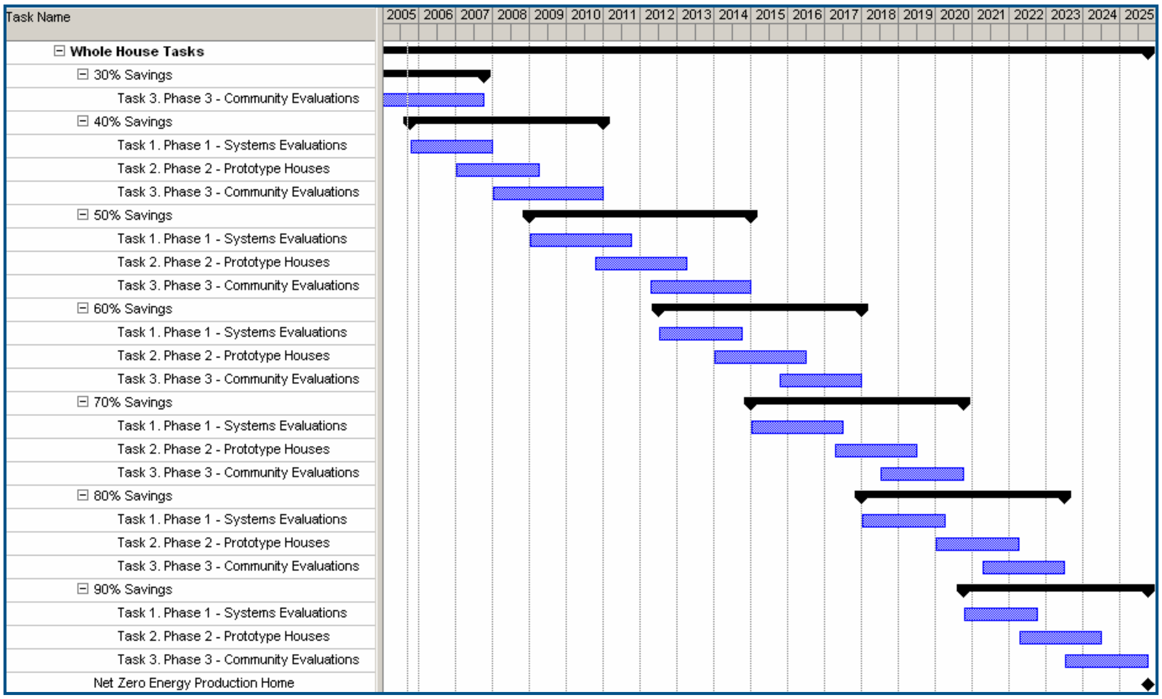
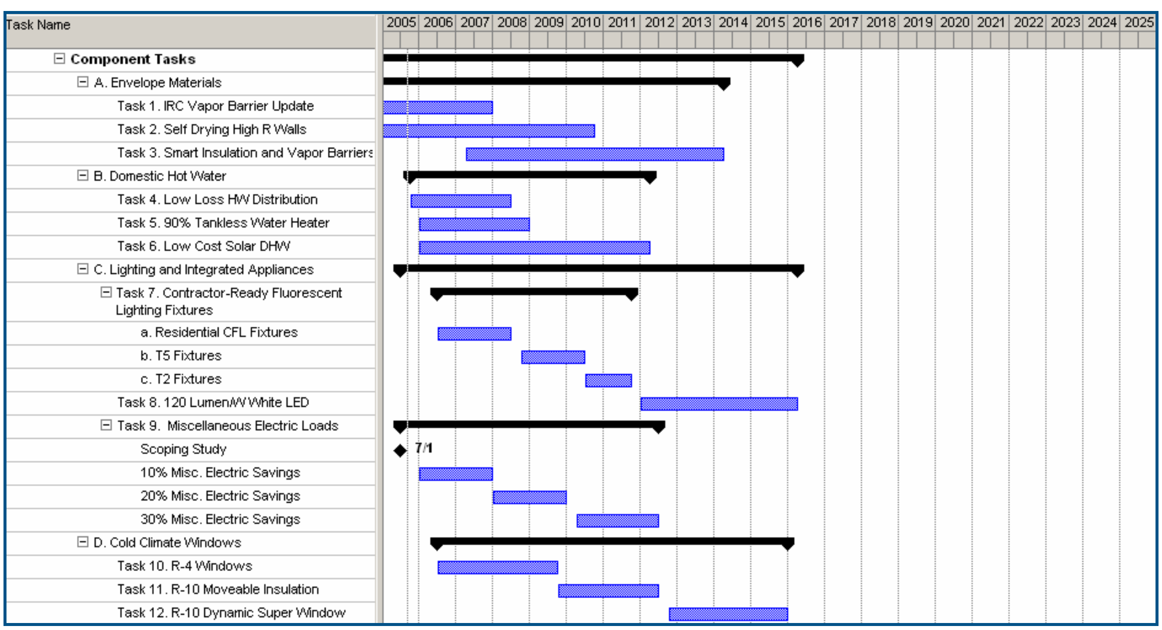


Figure 3-7 Residential System Component Needs



3.2 Commercial Integration

The Commercial Integration subprogram addresses energy savings opportunities in new and existing commercial buildings ($254 billion spent annually for new capital construction and $113 billion for renovation). This includes research, development and demonstration of whole building technologies, design methods and operational practices. Technology development efforts focus on cross-cutting, whole building technologies, such as sensors and controls and more energy efficient ventilation systems. These efforts support the ZEB goal not only by reducing building energy needs, but also by developing design methods and operating strategies, which seamlessly incorporate solar and other renewable technologies into commercial buildings.

Table 3-10 Commercial Integration Summary

Start date	1995
Target market(s)	Small and large commercial buildings
Accomplishments to date	Six case studies of High Performance commercial buildings
Current activities	Development of 30% better than code design guides Commercial Buildings Market Assessment Assessment of best type of design package Improved ventilation and IAQ Improved controls & diagnostics Continuous commissioning
Future directions	50% better than code design guides
Projected end date(s)	2025
Expected technology commercialization dates	Improved classroom HVAC – 2007 Improved UFAD systems – 2008 Wireless controls and diagnostics for rooftop HVAC – 2009 Automated Commissioning – 2010 UVPCO Advanced air cleaning – 2010

3.2.1 External Assessment and Commercial Integration Overview

Commercial buildings currently consume 47.5% of the total energy used by buildings, accounting for 19.7 quads in 2005. The commercial market is the second largest user of energy for buildings, but its energy use is increasing more rapidly than residential buildings.[19] By 2025, the commercial market will use as much as energy as the residential market.

The EIA provides twenty different classifications of commercial building types. These range from large, core-dominated hospitals, operated 24/7 to small retail stores operated for 10 hours, and from scientific laboratories with intensive ventilation and power

[19] BED

requirements, to houses of worship with relatively light and occasional energy requirements. There are many ways to characterize this heterogeneous sector, but one common approach is shown in Table 3-11**.**

Table 3-11 Commercial Buildings Types[20]

Building Type	Percent Total Energy Use	Primary Energy Intensity ($kBtu/ft^2/yr$)	Average Building Size (1,000 ft^2)
Warehouse	8%	86	17.4
Education	10%	135	26.5
Public Order	1%	139	16.2
Public Assembly	6%	167	14.4
Mercantile & Service	21%	180	25.0
Lodging	7%	196	29.5
Office	22%	218	16.3
Health care	8%	337	23.0
Food Service	7%	470	5.3
Food Sales	4%	532	5.7

Table 3-11 features 10 of the important EIA building types, characterized by energy use, and provides estimates from EIA's CBECS survey for both primary energy intensity and the share of the total energy pie. The data in the table are sorted from least to most energy intensive; grocery stores (food sales) are three times more energy intensive than retail stores, as a gross average for the respective sectors. Although this table offers some initial insight as to where BT might target its scarce R&D resources, the building type approach in fact has some limitations. Principally, it compels a discussion of building type, across 20 types of buildings[21], when in fact the buildings are more similar in many end uses than the table reveals.

The component technology approach to improved energy savings is adequate, but not sufficient because it doesn't account for interactions among components, such as lighting and air conditioning. A more robust energy savings approach is to consider the interactions among components by using computer simulation programs like EnergyPlus.

BT is considering other ways to approach energy savings besides design packages for new buildings. This study uses focus groups of industry leaders to identify what types of information these leaders would most likely consider in their building decisions. BT is also conducting a market analysis with what motivates the decision makers in purchasing new buildings. When these studies are completed and evaluated, the commercial building team will be better able to direct future research efforts.

[20] BED
[21] Not all types are shown in Table 11.

3.2.2 Internal Assessment and Commercial Integration History

Over the past several years, the High Performance Buildings (HPB) project has completed case studies of six buildings that are examples of what is attainable with an integrated systems approach. The key to this research was showing designers and owners that savings were actually achievable. The end result is a set of comprehensive technical reports on performance of buildings achieving from 40% to 70% reductions in energy use compared to applicable energy codes. Currently, the HPB project is working with two commercial buildings partners in the retail and food sales sectors. The design solutions will incorporate improved HVAC, lighting, advanced controls and sensors, and efficient ventilation among others.

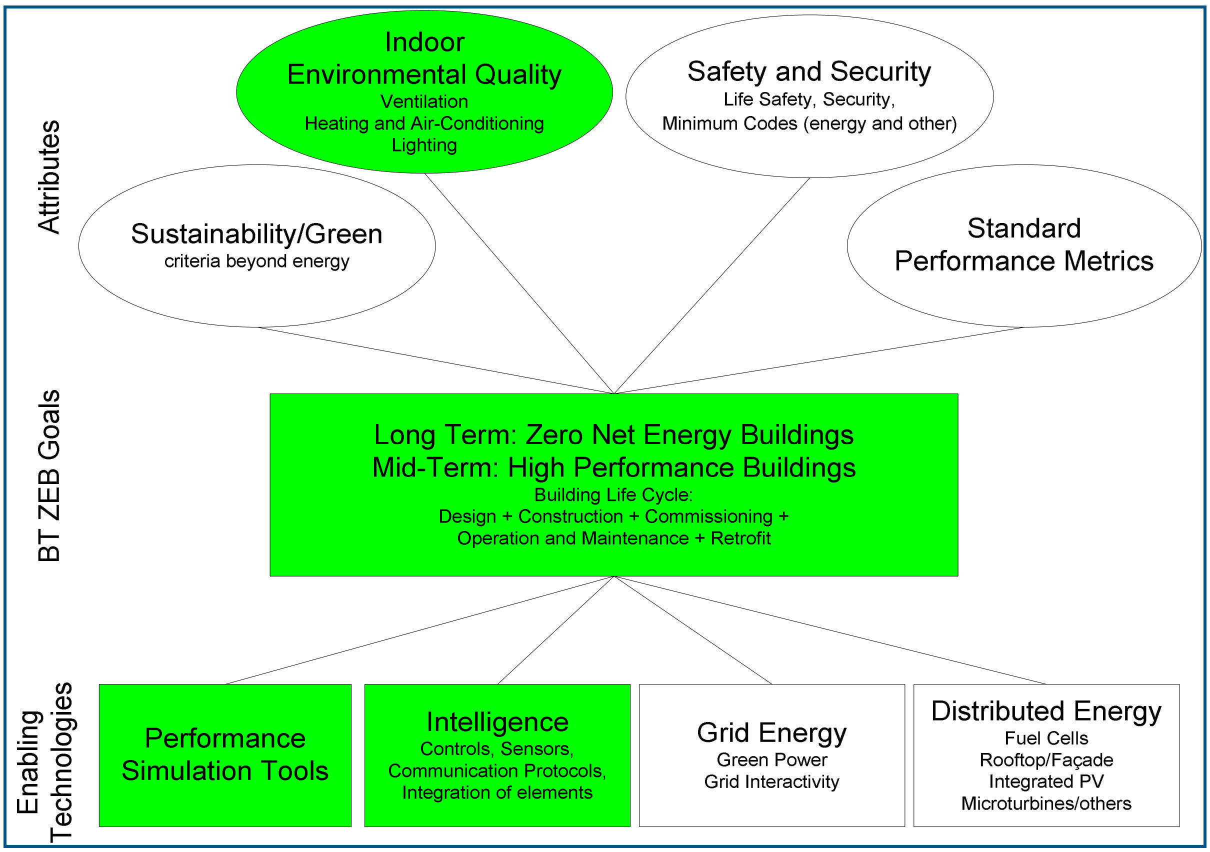
BT is continuing an active research agenda in High Performance Buildings in FY 2005, by focusing on the following:

- Providing technical assistance for the two retail store case studies in the form of engineering consulting, simulation of possible energy saving designs and analysis of current energy usage at existing stores. BT has completed a technical assessment of the opportunities to reduce energy use and move toward net-zero energy commercial buildings.
- Completing its definition of what is contained in design packages, through completing market assessments of what kinds of inputs are critical to help building owners decide about energy efficiency improvements to their buildings.
- Researching integrated controls with projects to develop building systems integrating controls and a wireless power sensor. BT initiated a project with commercial partners in FY 2005 to develop, test and demonstrate a rooftop HVAC unit with wireless controls and diagnostics. During this time, BT also began developing enabling technologies which will lead to an automated commissioning procedure and completed a report on commissioning of low energy buildings and a commissioning field test guide. In FY 2005, BT initiated a study of advanced controls and sensors to determine the issues and technology gaps. These results will help direct future controls activities and determine controls targets.
- Researching improved building ventilation systems to capture energy savings without adversely affecting occupant health. BT supported a revised ASHRAE ventilation standard for commercial buildings, developed and demonstrated an energy efficient classroom ventilation and air conditioning system, evaluated two advanced air cleaning systems and is testing and improving ventilation rate measurement systems for commercial buildings.

With commercial buildings using 18% of the nation's total energy consumption there is a real need to continue research to find ways to save energy in commercial buildings. To that end, the BT goal of ZEB is illustrated in the context of the national need in Figure 3-8. The circles on the top are important attributes of 2025 ZEBs. They include achieving a very low environmental footprint, which extends substantially beyond energy into water and materials and siting characteristics, to achieving high levels of good indoor environmental quality and to being safe and secure from natural or man-made disasters. The large box in the center represents the ZEB Goals and it is the main thrust of the high performance building research. The BT vision of net-zero energy commercial buildings includes the use of renewable energy sources to provide the balance of energy needed after energy conservation measures have been cost-effectively applied. The boxes on the bottom labeled as enabling technologies are important inputs and considerations in realizing net-zero energy buildings, including the development of simulation tools, intelligence technologies, grid and distributed energy.

The attributes also include the application of standard performance metrics to verify that the goal has been met. The metrics shown in the top circle are in many ways the keys to the kingdom. Without solid metrics of energy performance, there is simply no way to know and validate whether high or net-zero performance is actually being achieved. Performance metrics also provide consistency in terms and procedures.

Figure 3-8 Inputs to and Attributes of Net Zero Energy Commercial Buildings



BT's responsibilities are shown in the green or shaded areas in Figure 3-8. BT has the central role in the development of simulation tools and developing intelligence technologies. BT has no responsibility for the development of inexpensive and high performing PV systems because that responsibility is in the EERE renewable energy program. For attributes, BT's principal responsibility and expertise lay in Indoor Environmental Quality (IEQ), not in the broader categories of security and sustainability, which organizations and entities outside of DOE are concerned with. In the enabling technologies area, BT is responsible for developing simulation tools that pertain to building performance and building control or intelligence. Grid energy and distributed energy supply technologies are the responsibility of other EERE programs. Within the areas of responsibility shown in Figure 3-8 above, BT reviews its activities annually and selects those activities that are higher risk and therefore are less likely to be performed by the private sector, i.e., basic software engine development, testing and validation of advanced ventilation technologies, control protocol development, etc.

The Commercial Integration subprogram complements the Solar program, the Office of Electricity Delivery and Energy Reliability, the Distributed Energy Research program and other Federal Indoor Air Quality programs. In the solar, distributed energy and electricity energy areas, the BT commercial building subprogram considers these technologies in the design package development process. Solar PV and electrical energy peak reduction technologies will be described in the design packages depending on climate and building functions that make these technologies feasible and most likely to be used. The commercial buildings program will also consider electric energy peak reduction in its controls technology research. There is a project which considers the energy impacts of controls that reduce peak loads. There is a controls project with the National Building Institute that is developing standards for building information transfers. BT also works with the Federal Energy Management Program to implement and monitor the results of its research in certain Federal buildings.

3.2.3 Commercial Integration Approach

The challenges inherent in designing and operating high performance and net-zero energy buildings demand a number of breakthroughs, both in technology – including software and information technology – and in the fundamental knowledge of how to integrate and operate technology so as to optimize whole building performance. Systems integration and improved component technology (HVAC, lighting, windows, etc.) is required in order to achieve progressively higher levels of energy performance.[22] Also required is a much richer understanding of the market itself, given the heterogeneity of the commercial buildings subsector, which varies widely across the dimensions of size, surface-to-volume ratio, vintage of construction, complexity of function, owner versus lessor, and energy use. This understanding is necessary to target the R&D to realize the largest opportunities to save energy in real buildings.

A tractable and relevant strategic approach is provided in the 3 X 3 matrix below in Figure 3-9. This approach deliberately moves away from type to focus on three parameters that aid in characterizing the building as simple or complex and thus are near-

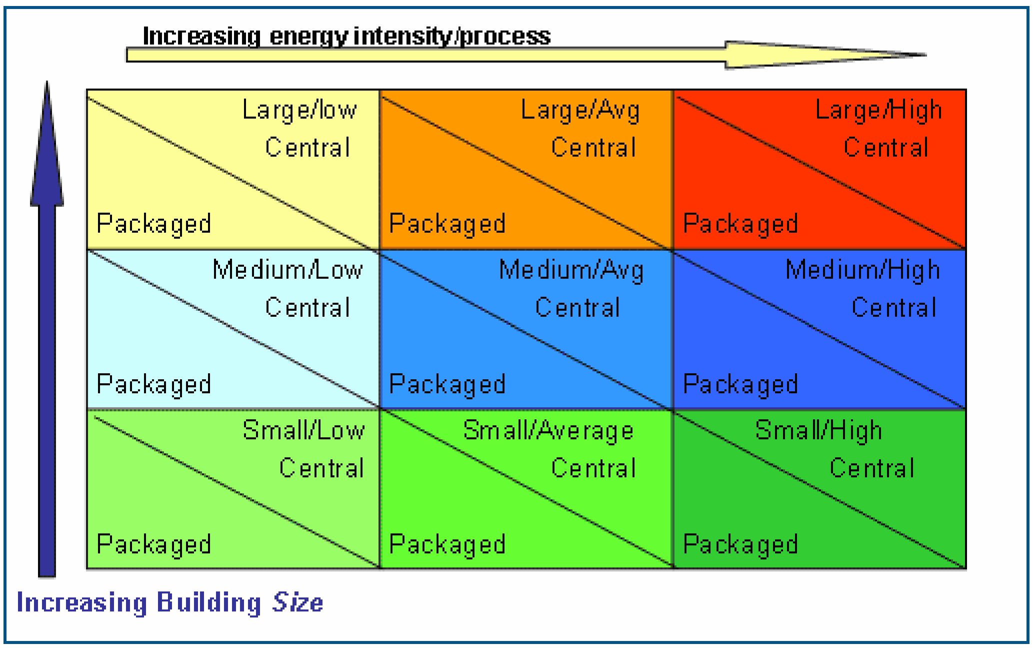
[22] By buildings "systems integration", we mean the design, construction and operation of the commercial building as an integrated system so as to maximize energy performance and occupant satisfaction. Careful daylighting design – for example – involves care in the specification of building orientation, window area, the performance of windows, interior design, and the control of electric lighting systems so as to maximize the use of natural light. A systems approach, as embedded in a "design package", will carefully integrate all of these factors to optimize building energy performance, including electric lighting and space heating and cooling.

or long-term candidates for application of net-zero energy concepts. The three parameters include:

1. The basic energy or process intensity of the building, grouped into low, average and high intensity;
2. The floor area of the building (size), grouped into small, average and large buildings; and
3. Whether the HVAC system is a central system (e.g., a chiller for cooling) or a packaged system (rooftop units). [Complexity of HVAC system]

As a general assertion, buildings of low to medium energy use intensities are more optimal candidates for application of zero energy approaches. This explains the general strategy of focusing the high-performance design package activity on average intensity buildings, as opposed to large core-dominated buildings.

Figure 3-9 Commercial Buildings Targeting Matrix by Size & Intensity



In this five year cycle, the Commercial Integration activities focus on repeatable building designs such as strip malls, retail stores, small (<25,000 ft^2) office buildings, schools, etc. BT has this focus because there are greater opportunities for energy savings (smaller commercial buildings can not afford large engineering budgets) and these buildings are replicated more times. BT will seek out opportunities to work with small commercial companies that build replicable buildings and are willing to take the risk to achieve 50% or more energy savings.

It is possible to design a building with 30 to 50 percent energy savings now compared to a building built to ASHRAE Standard 90.1-2004 if building envelope, lighting and mechanical systems are optimized in a whole-building package during early building design. In 2005, BT completed an optimization analysis to define a hierarchy of building performance levels that might be achievable in the marketplace over the next 20 years (see Table 3-12). This hierarchy recognizes that realizing "net zero" energy performance in actual buildings, from small offices to large hospitals, is a challenging, longer-term goal, and that a pathway of performance outcomes is appropriate, as demonstrated in the table below. This analysis will identify research gaps and help prioritize future research.

Table 3-12 Hierarchy of Building Performance Levels

Performance Level	Savings	Target Year
High Performance Buildings (HPB):		
Net Zero Energy Buildings (ZEB)	100%	2020 - 2025
Ultra-Low Energy Buildings (ULEB)	75%	2015 - 2020
Low Energy Buildings (LEB)	50%	2010-2015
Better Practice	20 – 30%	Available now
Conventional Good Practice (Code Compliant)	Baseline	

To realize the range of high performances shown above, from 50-100% over the next 20-25 years, DOE's technical approach will involve two distinct paths, as follows:

- High Performance Buildings using systems integration approaches, as embedded in design strategies, and;
- Integrated Systems Research that is critical to the efficient functioning of the building and equipment, such as controls, indoor environmental quality, and information technology applied to buildings.

High Performance Buildings
DOE's principal technical approach will be development of advanced design packages of system integrated design strategies and operational methodologies for HPB, which can be used by architects and others to design, build and operate commercial buildings in an integrated manner. Since the BT method actually validates the process with architects and engineers on real buildings, there are requirements for cost effective technology, marketability, maintenance of real estate value, building durability and grid connection reliability. Such an approach is clearly targeted at new construction because the opportunities for aggressive performance are so much greater than in existing buildings, where many building parameters (orientation, envelope, etc.) are set in steel and concrete. This does not exclude the renovation and existing building market, as many of the strategies can be deployed in this sector.

The advanced design packages will set the energy efficiency targets and answer the question, "How low can you go with current best available technology?" This is critical as current practice strives to be better than code, without much understanding of what is achievable and at what cost. Market research will help define the design packages. The design package will provide specific information for different audiences such as owners, developers, building architects and engineers, or deployment entities like utilities, states or municipalities. The design packages could range from a process guide for large buildings, a prescriptive package for smaller buildings or simply a software program for other types of buildings.

BT's approach to identifying a potential advanced design package is to find a building owner who is planning to build a new commercial building within the next year and who is willing to implement an integrated system approach. Key to success is the willingness for the private sector to take the risk and implement the recommended construction procedures and technologies. In return for the added risk, BT provides research-level analysis to the owner during the design, construction, commissioning and initial operating assistance. The building's performance will be verified by DOE's national laboratories and one or more contractors who will use BT's design development tools and system integration methods as well as performance metrics procedures.

The High Performance Buildings initiative improves the energy efficiency of commercial buildings in the United States.

The validation process will include an assessment of any issues, including code and technology that may need to be resolved before national implementation. The results of this process will be documented as design packages that DOE deployment activities such as FEMP and Rebuild America can use. The advanced design packages will be promoted through professional societies, trade journals and conferences and available to designers, builders, ESCOs, utilities, government agencies, and states.

Integrated Systems Research (ISR)
Other R&D activities using national laboratories and manufacturing partners will focus on development of building controls and communications protocols, or in some cases, application of existing technologies (wireless technology) to the particular requirements of buildings. Integrated building control logic and the interface between the building controls and the utility are two important areas to be studied. BT will determine the value proposition to the building owner, the utility, municipalities, states and regional/national security. After successful validation in buildings, these advanced controls and control logic will then be included in the design technology packages.

To move toward the goal of a zero energy building in new and existing commercial buildings, BT will develop integrating, continuous commissioning and predictive maintenance capabilities. The potential energy savings from these technologies range from 0.3 to 1.6 quads.[23] The tools may be adapted from existing technology such as in the nuclear industry.

The BT goal in the controls area is to help develop an advanced control system capable of integrating building systems by 2015. This goal contemplates a supervisory controller at the building level for the lighting, daylighting and HVAC systems. Additionally, DOE's national laboratories are developing control schemes that will make it easier for building managers to respond to demand signals from the utilities and to reduce peak loads with minimum disruption to their business practices, productivity and/or sales. By working with manufacturing partners, national labs and other government agencies, these advanced building controls will be deployed in the marketplace.

In six test building case studies completed by NREL in 2005 (funded by BT), daylighting was an integral energy savings feature—but in all six cases, the daylighting did not perform as expected. Because daylighting involves the interactions of glazing, shading, lighting, controls, and occupants, all the interactions must be carefully considered. In FY 2006, BT will investigate the technology challenges and barriers for daylighting and determine BT's potential role in this area, in cooperation with other BT subprograms, such as Windows.

After monitoring the energy consumption of the Oberlin College Lewis Center for Environmental Studies for two years, the National Renewable Energy Laboratory has released a technical report that presents the annual energy consumption of the Lewis Center by detailed end-uses and discusses lessons-learned in creating this low-energy building.

Commercial Integration is piloting a project to jointly develop a 30% design technology package on a specific building type with professional societies. This project will combine the strengths of BT's national laboratory analysis capabilities together with the expert experience of a working group of professionals and the publication and marketing force of a national organization. A working group will develop draft design guidelines for the selected building type and the national laboratories will simulate these energy efficiency measures in representative buildings in all of the U.S. climate zones. The working group brings the experience of designers and engineers together to decide on practical and cost effective solutions. Using the EnergyPlus simulation program and the BEOpt-C optimization tool, the national laboratories can determine the expected range of energy savings and evaluate the cost effectiveness of the suggested energy efficiency measures. This will ensure that the design guide meets its stated 30% energy savings goal most cost effectively. A critical part of this work will include field testing of the technology packages and assessment of market acceptance and practical application to buildings.

[23] *Energy Impact of Commercial Building Controls and Performance Diagnostics*, U.S. Department of Energy, Building Technologies Program. Prepared by TIAX LLC, November 2005. Report No. D0180.

3.2.4 Commercial Integration Strategic Goals

In order to reach net-zero energy buildings by 2025, DOE will develop integrated whole-building strategies to enable commercial buildings to be designed, constructed, and operated to use 70 percent less energy relative to ASHRAE Standard 90.1-2004. The balance of the buildings' energy requirements (30%) will be met by renewable energy sources.

3.2.5 Commercial Integration Performance Goals

Going forward, the Commercial Integration team will collaborate with ASHRAE, AIA, IESNA, USGBC, and other appropriate partners to develop advanced design guides for small and medium-sized commercial buildings. By 2009, the BT goal is to develop the initial series of five advanced design guides at 30% above ASHRAE Standard 90.1-2004. The effort will set out a prioritized schedule that allows for adaptation of information generated in initial guides in the series and focuses effort on specific needs of each new guide. Further, the effort will lead (with positive peer review and market impact assessment of initial efforts) to collaborative work on a second series of guides at 50% above 90.1-2004 (or an adjusted baseline, if appropriate).

Table 3-13 High Performance Buildings Performance Targets

Characteristics	Units	Calendar Year		
		2006	2009	2011
Whole Building Energy Use Target Reductions	% Energy Savings	30	30	50
Advanced Design Guides for Small and Medium Sized Buildings	Number	1	5(draft)	5(draft)

As shown in Table 3-14, BT has begun a series of studies and assessments in Integrated Systems Research to identify the technical pathways and appropriate government role in Commercial Integration. Most of these assessments will be completed in FY 2006 and will then be used to determine appropriate efficiency and performance metric targets. Studies already completed have shown that we can reduce energy use by 15% by implementing system commissioning procedures at least once during a building's lifecycle.

Table 3-14 Integrated Systems Research Targets

Characteristics	Units	Calendar Year		
		2006	2009	2011
Commissioning and O&M	Reports and Assessments	0	1	TBD
Integrated Building Controls	Reports and Assessments	1	1	TBD
Integrated On-Site Power Controls	Reports and Assessments	0	1	TBD

Daylighting	Reports and Assessments	1	1	TBD
IAQ	Reports and Assessments	3	2	TBD

3.2.6 Commercial Integration Market Challenges and Barriers

Table 3-15 Commercial Integration Market Challenges and Barriers

Barrier	Title	Description	Target
A	As Built versus Design	When construction changes are needed (for scheduling or product availability), the solutions must be evaluated consistent with the design goals.	HPB
B	Building Commissioning not Common Practice	Building commissioning should make the building operate according to the design intent and must look at the entire building system.	HPB
C	Integration of on and off Site Power and Demand Side Management often not Considered during Design	Other groups within EERE are developing energy supply technologies like gas cooling, solar thermal and PV, fuel cells, micro-turbines and combined heat and power technologies. Other groups within DOE, CEC and the national labs are developing Demand Reduction capabilities.	ISR
D	Maintaining Best Operations Practice usually not done	Current Operations and Maintenance (O&M) practice of new and existing commercial buildings is frequently poor and can increase building energy use by as much as 30 percent.	ISR

3.2.7 Commercial Integration (Non-Market) Challenges/Barriers

Table 3-16 Commercial Integration Technical Challenges/Barriers

Barrier	Title	Description	Target
E	Inherent Complexity of Daylighting Practices	A barrier to daylighting is its inherent complexity – a number of elements must be carefully integrated to ensure savings result.	HPB
F	Integrated Building Controls Systems Usually Are Underutilized	Even when energy management and control systems are present, their capabilities are often not fully utilized nor even understood by the operators.	ISR

Barrier	Title	Description	Target
G	No Single Definition of "Good" Building Energy Performance	Standard metrics for fuel economy exist for cars and light trucks, allowing for comparisons of energy performance and annual energy costs between models. Similar metrics for commercial buildings simply do not exist, so most building managers have no idea if they are operating their buildings efficiently or poorly.	ISR
H	Good IEQ Requires more than Ventilation	Designers usually specify the code required ventilation and assume that good IEQ will happen, which tends to provide minimum cost, high energy solutions to IEQ.	ISR
I	Establish Scientific Basis for Minimum Ventilation Requirements	By extrapolating from studies in office buildings, we suspect that human health, work, and performance may depend on providing clean and uncontaminated air in buildings. However, there are few data indicating how ventilation rates affect health, performance, and learning. Thus, existing minimum ventilation rate standards established for these buildings are based primarily on judgment and anecdotal experience.	ISR

3.2.8 Commercial Integration Strategies for Overcoming Barriers/Challenges

Table 3-17 Commercial Integration Strategies for Overcoming Market Barriers/Challenges

Barrier	Title	Strategy
A	As Built versus Design	Procedures must be developed to ensure that building construction follows the plan. Common gaps should be identified between design intent and as-built performance.
B	Building Commissioning not Common Practice	Commissioning practices and tools should evolve to support high performance buildings. The reasons should be determined why so few buildings are commissioned when the average energy savings are 15% or more.
C	Integration of on and off Site Power and Demand Side Management often not Considered during Design	The design and construction practices that will optimize these resources need to be determined. Adding on-site generation, probably along with real-time management of loads to minimize expenditures from the electric power grid, would overwhelm most building operators. The amount of building automation needed to enable management and control of these systems should be determined.
D	Maintaining Best Operations Practice usually not done	Identify the types of tools, controls, sensors and software needed to get buildings to perform as designed.

Table 3-18 Commercial Integration Strategies for Overcoming Technical Barriers/Challenges

Barrier	Title	Strategy
E	Inherent Complexity of Daylighting Practices	Demonstrate integrated solutions of fenestration, lighting systems, and controls which reduce the overall lighting energy requirements by more than 40%.
F	Integrated Building Controls Systems Usually Are Underutilized	Develop control algorithms and strategies, interfaces and other enabling mechanisms to ensure that buildings are operated efficiently.
G	No Single Definition of "Good" Building Energy Performance	Develop additional whole building performance metrics and procedures as required to support the design technology package.
H	Good IEQ Requires more than Ventilation	Reduce energy used for ventilation through a combination of source control, air cleaning and ventilation.
I	Establish Scientific Basis for Minimum Ventilation Requirements	Conduct research to develop a defensible basis for establishing ventilation requirements.

3.2.9 Commercial Integration Tasks

Table 3-19 lists the key tasks BT will focus on in the Commercial Integration activity over the next 5 years.

Table 3-19 Commercial Integration Tasks

Task	Title	Duration	Barriers
1	Advanced Design Guides for Small Buildings: Develop design technology packages for new high performance small and medium sized commercial buildings	20 quarters	A. As Built versus Design
2	Optimization Study	8 quarters	C. Integration of on site and off Site Power and Demand Side Management often not Considered During Design
3	LEED Version 3	8 quarters	Need to determine the effectiveness of the current LEED.

Task	Title	Duration	Barriers
4	Commercial Building Benchmark	4 quarters	G. No Single Definition of "Good" Building Energy Performance
5	Integrated Building Controls: Develop and validate design guidance on optimal ways to integrate building loads and on-site power systems Conduct a controls study and assessment to determine the barriers, technology pathways and appropriate government role	12 quarters 4 quarters	C. Integration of on and off Site Power and Demand Side Management often not considered during design, F. Integrated Building Controls Systems Usually Are Underutilized
6	Commissioning & O&M:Define and develop the next generation of commissioning and diagnostic procedures for high performance buildings	12 quarters	B. Building Commissioning not Common Practice, D. Maintaining Best Operations Practice Usually not Done
7	Integrated On-site Power Controls	TBD	C. Integration of on and off Site Power and Demand Side Management often not considered during design
8	Daylighting: Assess, develop, test, and field demonstrate integrated solutions of fenestration, lighting systems, and controls	16 quarters	E. Integration of Daylighting Practices
9	IEQ Technologies Development and Evaluation	20 quarters	H. Good IEQ requires more than Ventilation

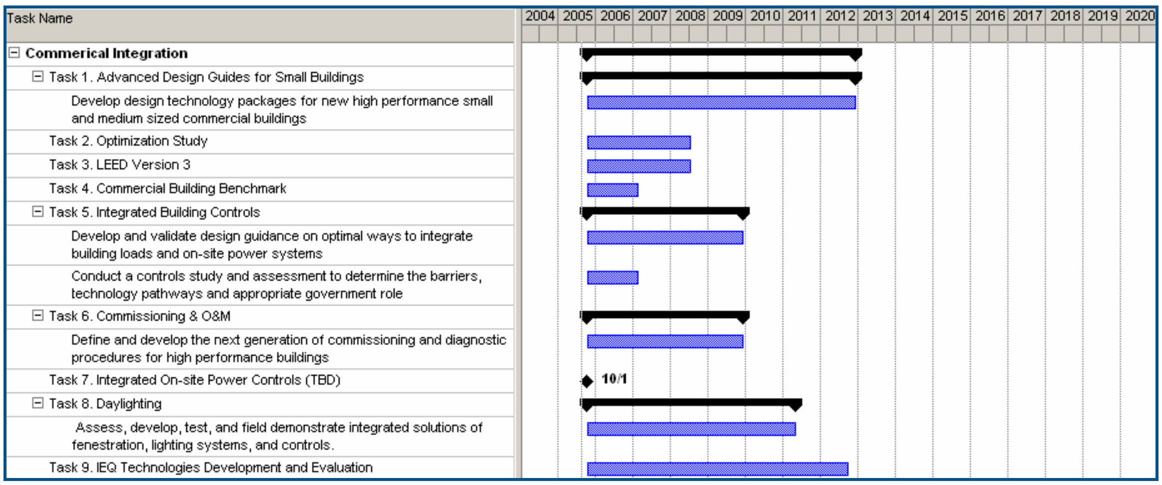
3.2.10 Commercial Integration Milestones & Decision Points

The Gantt chart shown below, Figure 3-10 identifies Commercial Integration key activities in high performance buildings and integrated systems research. In the area of HPB, BT will conduct three assessments to help guide the program design of this activity through 2010. They include:

1. Participation in the development of the ASHRAE 30% Design Guides for small commercial buildings;
2. Analysis to determine the HPB construction and design products actually desired by the market;
3. Determination of the level of DOE involvement in developing the energy-efficiency criteria of the Green Building Council's next version of the LEED rating (Version 3);
4. Evaluation of technology pathways resulting from the BEOpt commercial building optimization studies; and
5. Participation in an ASHRAE sponsored building ventilation workshop.

For the Integrated Systems Research portfolio, much activity here is focused on conducting technical and market opportunity assessments (Step 2) and ranking the opportunities relative to each other (Step 3). All of this is necessary to determine a robust systems research portfolio, one derived from the results of analysis. That is why there are a number of workshops and studies in the near term in the Gantt chart, and also why a number of "go/no-go" decision points are featured for controls, O&M and daylighting. For each "go/no-go", DOE shall determine the level of potential savings, the need for technological breakthrough, and whether or not the role is inherently Federal.

Figure 3-10 Commercial Integration Gantt Chart



3.3 Lighting

Table 3-20 Conventional Lighting Summary

Start date	1978
Target market(s)	Residential, Commercial, Industrial and Outdoor Stationary; both new and retrofit
Accomplishments to date	• Research on phosphors with GTE in late 1970's • Developed, tested, and field-tested electronic ballasts for fluorescent lamps • Enhanced spectrum lighting and energy efficiency – tested and demonstrated • More than twenty-five patents awarded • Several fundamental technical/reference reports for lighting industry • Formulated and participated in several key industry symposia and roadmapping activities

Current activities	• Higher efficiency incandescent filaments through research into selective-emitters • Fluorescent lighting with carbon nano-tube cathode research • Lighting controls systems, including improvement of dimming ballasts and lamps • Wireless control system installation to reduce commissioning costs • Novel nanophosphor research for high efficiency fluorescent lamps • Energy savings through spectrally enhanced light sources
Future directions	• Transition technologies that have completed their development cycle (achieved a level of technical maturity for commercialization/implementation) out of the Lighting subprogram to other appropriate areas (off-ramps) • Research conventional technologies that supplement and challenge research in academia, national labs and industry to drive lighting technologies to higher efficiency and performance goals • Address technology development opportunities in high-intensity discharge lighting that would enhance market-readiness of this energy saving opportunity by lowering the cost, reducing the size and expanding the appeal to more applications
Projected end date(s)	• Light sources research will be on-going. • Activities in lighting controls and fixtures will be transitioned to Building Integration subprograms for inclusion in the building controls system and/or to emerging technology and market transformation program areas (e.g., Appliances Codes and Standards, Emerging Technologies, Energy Star) to increase market penetration, by end of FY 2006. • Activities in spectrally enhanced light sources and other human-factor related projects will be transitioned to Building Integration subprograms for inclusion in other BT program areas, including market transformation, by end of FY 2006.
Expected technology commercialization dates	• Many conventional lighting technologies (e.g., the electronic ballast and CFLs) are already commercialized, and have benefited from DOE investment in R&D. • Lighting controls systems and communication protocols are already commercialized, but the market penetration is insignificant. Hence, there is a need to transition this research area.

	• In the period between 1978 and 2001, DOE Lighting R&D has generated more than twenty-five patents.

Table 3-21 Solid-State Lighting Summary

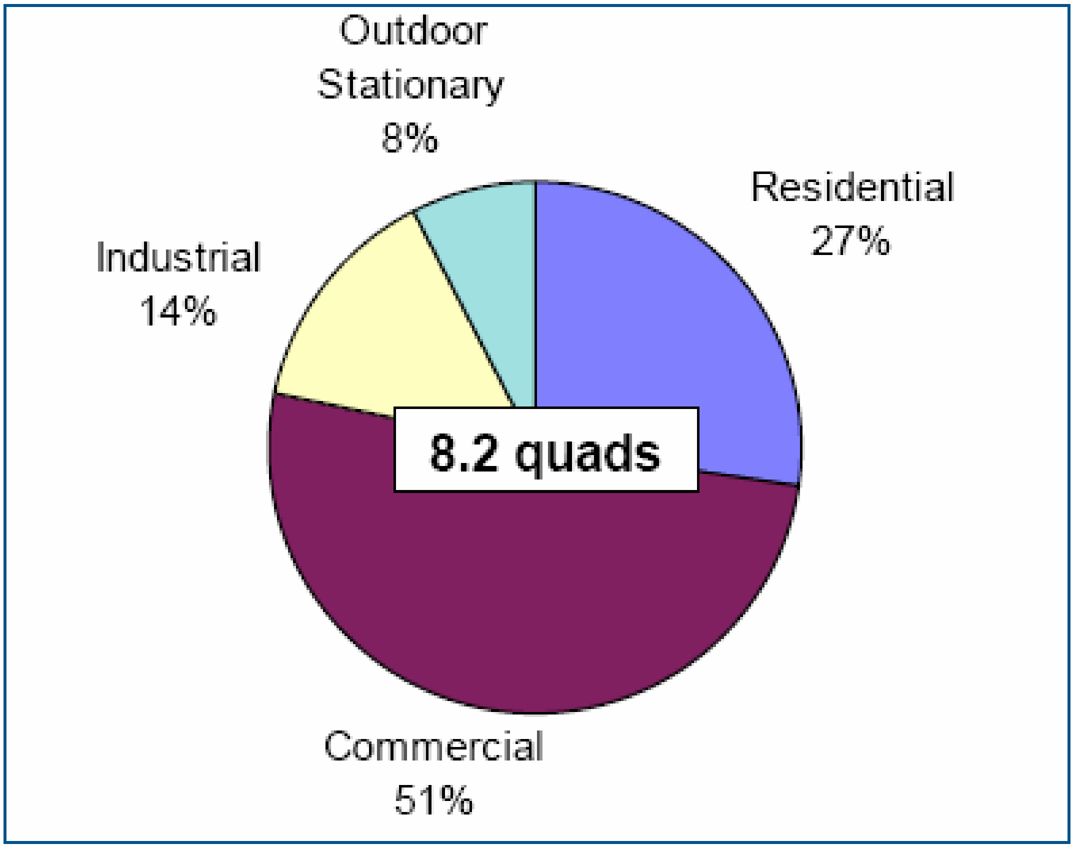
Start date	2001
Target market(s)	• Commercial and Residential specialty, task and directional lighting applications (e.g., MR16, PAR38) • 2015-2025: All sectors, general illumination
Accomplishments to date	• 2004, Sandia National Laboratories received an R&D 100 Award for development of a new process for growing gallium nitride on an etched sapphire substrate. • 2003, two research partners, Dr. George Craford of Lumileds Lighting and Russell Dupuis of Georgia Institute of Technology, were awarded the National Medal of Technology by the President. • World record - Lumileds Lighting teamed with Sandia National Laboratories to develop semiconductor nanoparticles ("quantum dots") with light conversion yields of up to 76 percent. • World record - General Electric Global Research teamed with Cambridge Display Technologies to develop an OLED light panel that produces 1200 lumens of white light at 15 lumens per Watt at a color rendering index greater than 94. • World record - Significant advances in chip technology enabled Cree, Inc.'s Santa Barbara Technology Center to demonstrate white LEDs with a record efficacy of 74 lumens per Watt. • World record - Universal Display Corporation teamed with Princeton University and the University of Southern California to develop low voltage, high efficiency white phosphorescent OLEDs that achieved a record 20 lumens per Watt.
Current activities	• High efficiency visible and near-UV semiconductor materials for LED based general illumination technology • Advanced architectures and high power conversion efficiency emitters • High temperature, efficient, long-life phosphors, luminescent materials for wavelength conversion and encapsulants • LED luminaire design and materials • High efficiency, reliable, intelligent electronics for LEDs • High efficiency, low-voltage, stable materials for OLED-based

	general illumination technology (hosts, dopants, and transport layers) • Strategies for improved light extraction and manipulation • Novel device structures for improved performance and low cost • OLED luminaire design and materials • High efficiency, reliable, intelligent electronics for OLEDs
Future directions	• Continue to drive development of more energy-efficient, white-light SSL sources through research in both inorganic and organic technologies • Continue to work both in the core technology and product development arenas, creating partnerships between academia, research labs and industry to create more energy-efficient SSL technologies • Initial emphasis on core technology to accelerate development of more robust, energy-efficient SSL devices • Later, emphasize product development activities, to improve manufacturing capabilities, reduce costs and encourage market penetration • Continue to work through collaborative partnerships, competitive solicitations and consultative R&D prioritization processes • Hold annual meetings with the SSL community to solicit input on the prioritization of the SSL R&D portfolio
Projected end date(s)	• The SSL R&D team estimates that by 2025, it will have achieved the objective of a technical capability of illuminating our buildings using 50% less electricity than lighting technologies in 2005. The projected end-date of the SSL R&D initiative is 2025. • The emphasis of the program on core technology and product development will be managed over time, with initial emphasis on core technology.
Expected technology commercialization dates	• Energy Star will launch a fixture design competition for SSL fixtures in FY 2007, at which point the efficiency of commercially available SSL technology will have noticeably exceeded incandescent (3 to 5 times better, 50 to 75 lumens per Watt). • SSL R&D will continue to collaborate with those BT subprograms and other appropriate market transformation and implementation initiatives at DOE to assist in accelerating adoption of the energy efficient technology.

3.3.1 External Assessment and Lighting Market Overview

Energy consumption for all lighting in the U.S. is estimated to be 8.2 quads, or about 22% of the total electricity generated.[24] On a national basis, Figure 3-11 provides a break-down by end-use sector of the energy consumption for lighting our homes, offices and other metered applications around the country. The figure shows that more than half of these 8.2 quads were consumed in the commercial sector, the largest energy user for lighting. This is one of the principle markets the DOE has targeted to develop more efficient technologies, as lighting contributes to a building's internal heat generation and subsequent air-conditioning loads at peak times.

Figure 3-11 National Primary Energy Consumption for Electricity for Lighting, 2001[25]



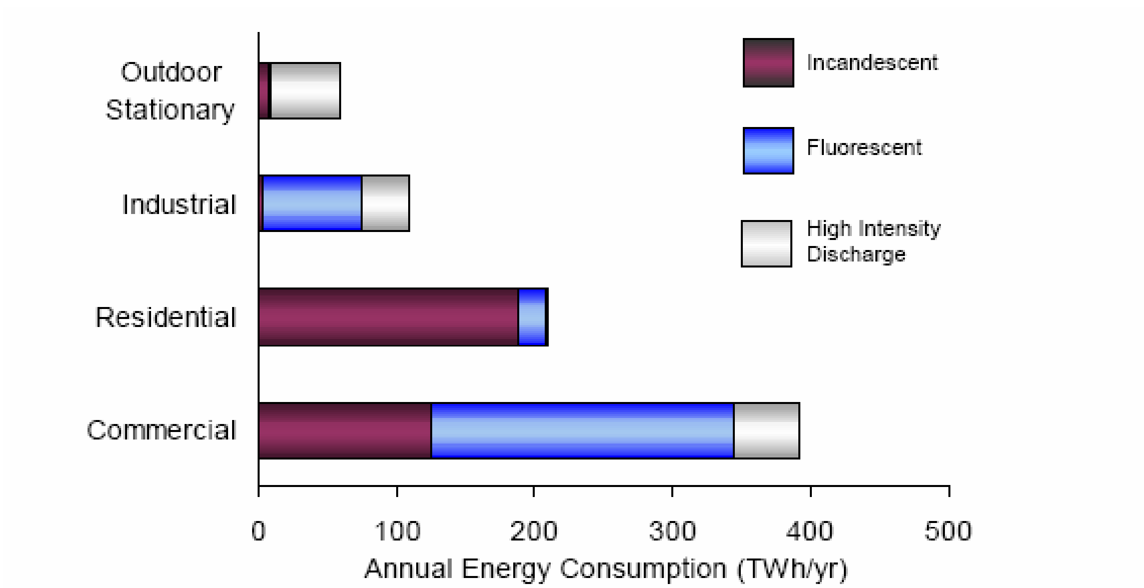
Looking only at the commercial and residential sectors, the total energy use for lighting was approximately 6.4 quads.[26] Nationally, total energy use in commercial and residential buildings was approximately 36.4 quads, of which electricity use was approximately 21.3 quads.[27] Thus, in these two building sectors, lighting constituted

[24] *U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate*, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program. Prepared by Navigant Consulting, Inc., November 2003. Hereafter, LMC I.
[25] LMC I
[26] LMC I
[27] BED

approximately 18% of total building energy consumption, or approximately 30% of total building electricity use.

The figure below illustrates the breakdown by sector of national energy consumption for lighting in units of site electricity consumption (terawatt-hours/year), disaggregated by source type. These units represent the electrical energy consumed on-site for lighting throughout the United States.

Figure 3-12 National Lighting Energy Consumption by Sector & Source[28]



The figure shows that fluorescent sources in the commercial sector are the single largest lighting energy-consuming segment in the U.S., slightly greater than incandescent lamps in the residential sector. However, across all sectors, incandescent is the leading electricity consumer in the U.S. consuming 321 terawatt-hours per year (TWh/yr). Fluorescent lighting is a close second with approximately 313 TWh/yr and HID is third with approximately 130 TWh/yr.[29]

3.3.2 Internal Assessment and Lighting History

Lighting loads are significant in all climate regions of the U.S. (i.e., uniform applications) and considerable energy savings could be realized through the development and use of high-efficiency light sources. The Lighting subprogram activities in BT address these opportunities by supporting research into new and conventional light sources, light fixtures and controls, and human factors. The lighting activities began in the 1970's, and the present program structure is the result of years of consultation with industry partners and stakeholders.

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[28] LMC I
[29] LMC I

The Lighting subprogram encompasses two active areas of emphasis, conventional lighting technologies (e.g., incandescent, fluorescent and high-intensity discharge), and the more recent solid-state lighting technologies including inorganic light-emitting diodes and organic light-emitting diodes. The program histories of these two areas are presented separately, as the technical activities of the past, present, and future are different.

The conventional technology activities encompass and address products that have been commercially available for decades. In some cases, national regulatory standards (including energy efficiency) impact these technologies, and well-established industry associations exist that develop standards and harmonize technology communication protocols. The projects undertaken over the last three decades have tended to focus on incremental research activities with high commercialization potential; however, there has not been a consistent theme, direction or organizational framework. In the absence of an over-arching direction, some projects were supported that sought to develop redundant technologies that were a complete departure from industry and market trends (zero market potential).

While energy-efficiency has been identified as an objective of these activities, the Lighting subprogram could benefit from a greater degree of consultation with industry and research experts to carefully prioritize its R&D agenda. This consultation took place in 2003 and 2004, and is ready now to be applied to the conventional technology R&D activities.[30] A broad group of experts, including industry representatives, academia, researchers, and lighting consultants and designers were asked to review and rank more than 180 research activities that have the potential to reduce energy consumption in lighting. This review involved two rounds of consultation, where options were selected and then further developed into a list of the recommended areas of research. Of the conventional light sources, the section on high-intensity discharge lamps received the bulk of the support, with specific interest focused on R&D activities in metal halide high-intensity discharge lamps. Though introduced in the 1960's, this technology is still being improved in terms of light quality, energy-efficiency, operating life, and re-strike capability. It has already demonstrated its ability to replace incandescent lamps in automobile head-lights, realizing a more than two-fold improvement in efficacy. As this technology continues to evolve and improve, new applications will be realized and energy efficiency opportunities captured. For this reason, the future directions of the conventional lighting R&D activities are focused on high-intensity discharge lamps.

SSL is a revolutionary technology that holds the promise of significantly reducing national energy consumption. Solid-state technology represents a rare and unique opportunity to revolutionize an industry with a more efficient, better performing and more easily controlled building technology. Experts agree that over the next few decades, SSL sources will begin to compete with conventional technologies in general-illumination applications, and ultimately, may become the dominant source of electric lighting. In this dynamic market, the Lighting portfolio plays a critical role facilitating

[30] *U.S. Lighting Market Characterization, Volume II: Energy Efficient Lighting Technology Options*, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program. Prepared by Navigant Consulting, Inc., September 2005.

partnerships, supporting research and emphasizing energy-efficiency. Just as in the 1950's when plastics were named as the material of the future and the transistor trumped the vacuum tube, so solid-state lighting is projected to become the lighting technology of the future.

3.3.3 Lighting Approach

The R&D agenda of the SSL R&D portfolio is established through an annual consultative process with academics, laboratory researchers, industry scientists and other technical experts and stakeholders. The high priority tasks of the R&D agenda are the scope of a competitive solicitation. Proposals are submitted and awards are made to the proposals that focus on these tasks and who contribute to DOE efficiency goals.

The solid-state lighting program classifies its projects into a two-by-two matrix, creating four R&D super-classes: LED Core Technology, LED Product Development, OLED Core Technology and OLED Product Development. Within each super-class, there are active, detailed R&D agendas which contribute to the larger programmatic objective. Core Technology and Product Development are defined as follows:

Core Technology
Core Technology research includes scientific efforts that seek to gain more comprehensive knowledge or understanding of the subject under study, with possible multiple applications or fields of use in mind. Within Core Technology research areas, scientific principles are demonstrated, and the knowledge is shown to offer price or performance advantages over previously available science/engineering. Laboratory testing and/or math modeling may be conducted to gain new knowledge, and provide the options (technical pathways) to a SSL application. Activities could include theory, fabrication, and measurement of a material to provide the detailed understanding (properties and relationships) that solve one or more of the technical challenges of the DOE SSL program. Tasks in Core Technology are truly innovative and groundbreaking, fill technology gaps, provide enabling knowledge or data, and represent a significant advancement in the SSL knowledge base. These tasks focus on gaining pre-competitive knowledge for future application to products, for use by other organizations. The desired outcome is pioneering work that would be available to the community at large, to use and benefit from as they work collectively towards attainment of the DOE's efficacy goals.

Some examples: theoretical investigations of light generation and extraction at molecular scales; material properties of substrates, encapsulants, or polymers; software tools that capture scientific principles to expedite the decision process of design; modeling of heat transfer principles to estimate temperature profiles within a semiconductor reactor; and mapping of scientific principles that explain the interactions of dopants and hosts or metal alloys to create light of a specified spectrum.

Product Development
Product Development is the systematic use of knowledge gained from basic and applied research to develop or improve commercially viable materials, devices, or systems. Technical activities are focused on a targeted market application with fully defined price,

efficacy, and other performance parameters necessary for success of the proposed product. Product development encompasses the technical activities of product concept modeling through to the development of test models and field-ready prototypes. In some cases, product development may include focused-short-term applied research, but its relevance to a specific product must be clearly identified.

Laboratory performance testing is conducted on prototypes to evaluate product utility, market, legal, health, and safety issues. Feedback from the owner/operator and technical data gathered from testing are used to improve prototype designs. Further design modifications and re-testing are performed as needed.

Along with the technical aspects of product development, market and fiscal studies are completed to ensure a successful transition from product development to demonstration and commercialization. To be positioned for success, new products must exhibit cost and/or performance advantages over commercially available technologies.

3.3.4 Lighting Strategic Goals

The Lighting portfolio is a critical subprogram of the larger Building Technologies Program. Its strategic goal clearly states where the program is headed in terms of energy savings. The objective is not tied to any one technology or approach, but rather encompasses a portfolio of activities and states the anticipated outcome. The Lighting strategic goal reads as follows:

By 2025, develop and demonstrate energy-efficient, high-quality, cost-effective, long-lasting lighting technologies that have the technical capability of illuminating our buildings using 50% less electricity compared to technologies in 2005.

This strategic goal establishes a target of developing technologies that consume 50% less energy than lighting technologies in 2005. The objective incorporates two critical components – an energy savings target and a device performance target. The following text discusses these two pillars of the technical objective.

The energy savings goal ties back to the BT Program mission of increasing the energy efficiency of buildings and the concomitant benefits associated with those savings. The objective sets a goal of "fifty percent less electricity compared to [lighting] technologies in 2005." This comparison is looking at the replacement not of incandescent technologies (although these are in use in 2005), but the more efficient fluorescent sources, which were identified as the largest single user of electricity for lighting in commercial buildings. Linear fluorescent lamps operating in a system (including ballast and fixture losses) can offer efficacies as high as 80 lumens per Watt. Compact fluorescent lamps, a derivative of this technology, are less efficient (approximately 60 lumens per Watt); however, they still offer a four-fold improvement over incandescent. In this technical objective, Building Technologies is targeting the development of solid-state lighting devices and technologies that will have the capability of producing light at more than double those of fluorescent technologies. Efficacies in excess of 160 lumens per Watt for market products are projected, with 200 lumens per Watt targeted for the laboratory.

3.3.5 Lighting Performance Targets

The performance targets for conventional technology and solid-state lighting are shown below. Separate targets were developed for each, to accommodate different metrics of performance used by experts in each field, and to account for differences in the applications where these technologies will be installed.

For conventional lighting technologies, the performance target is focused on commercial buildings, which have the largest energy consumption of any sector/technology combination. The units of this performance target are Watts per square foot, indicating the power (energy consumption) density per unit area. This metric is widely used in new building construction codes, such as ASHRAE 90.1, and state energy standards, including California's Title 24. The table below shows the ASHRAE 90.1 lighting power density levels for the existing standard (ASHRAE 90.1-1999) and the proposed standard under consideration by the ASHRAE committee. This table shows a small sample of the range of building area types contained in 90.1.

Table 3-22 ASHRAE 90.1 Existing and Proposed Lighting Power Density Levels

Building Area Type	Existing Levels (watts per square foot)	Proposed Levels (watts per square foot)
Automotive Facility	1.5	0.9
Convention Center	1.4	1.2
Court House	1.4	1.2
Dining: Bar Lounge/Leisure	1.5	1.3

The table below shows the California Title 24 lighting power density levels for the existing standard and the proposed standard under consideration. This table shows a small sample of the range of applications contained in Title 24.

Table 3-23 California Title 24 Existing and Proposed Lighting Power Density Levels

Type of Use	Existing Levels (Watts per square foot)	Proposed Levels (Watts per square foot)
Auditorium	1.5	1.5
Convention Center	1.3	1.3
Financial Institutions	1.1	1.1
General commercial and industrial work buildings: High bay	1.2	1.1

In 2001, the national average lighting power density of commercial office space was 1.8 watts per square foot.[31] Assuming a typical luminaire coefficient of utilization of 0.40

[31] LMC I

and an illuminance of 40 foot-candles (fc) for a typical office space, this translates into a light source efficacy of 55.6 lumens per Watt. This level is consistent with the average weighted efficacy of 55.2 lm/W calculated for the entire commercial sector.[32] Presently, ASHRAE 90.1-1999 and California's Title 24, which apply to newly constructed buildings or major renovations, both place restrictions on lighting power density at 1.3 Watts per square foot for an office space. Both ASHRAE 90.1 and Title 24 are currently under revision, and the draft proposed limits on lighting power density for an office space will decrease to 1.0 and 1.1 Watts per square foot, respectively. The Lighting activities on conventional technologies would augment this industry direction, by increasing the availability of energy efficient lighting technologies and systems to achieve and meet the lighting power density. The table below shows the efficacy required to achieve minimum illuminance for a typical office under the various power density scenarios.

Table 3-24 Efficacy Required Under Power Density Scenarios for Office Application

Scenario	Power Density	Estimated Coefficient of Utilization	Target Illuminance	Required Efficacy
LMC 2001	1.8 W/ft^2	0.4	40fc	56 lm/W
ASHRAE existing	1.3 W/ft^2	0.4	40fc	77 lm/W
ASHRAE proposed	1.0 W/ft^2	0.4	40fc	100 lm/W
Title 24 existing	1.2 W/ft^2	0.4	40fc	83 lm/W
Title 24 proposed	1.1 W/ft^2	0.4	40fc	91 lm/W
Lighting R&D	0.9 W/ft^2	0.4	40fc	111 lm/W

Lighting activities in conventional lighting technology will decrease the lighting power density per unit area. In 2001, the national average lighting power density was approximately 1.8 Watts per square foot for the commercial sector.[33] The installed base is estimated to be approximately 1.5 Watts per square foot in 2005 due to efficiency improvements. Over the next two decades, the installed base of lighting in commercial buildings, with new technologies and capabilities provided by the Lighting activities, is projected to decrease from 1.5 in 2005 to 0.9 Watts per square foot in 2025. This reduction is attributable to market-driven efficiency improvements as well as new construction codes (e.g., ASHRAE 90.1 and California's Title 24) and on-going industry and government research activities in conventional lighting technologies. This reduction represents a forty-five percent savings over the 2001 level of 1.8 Watts per square foot.

[32] LMC I
[33] LMC I

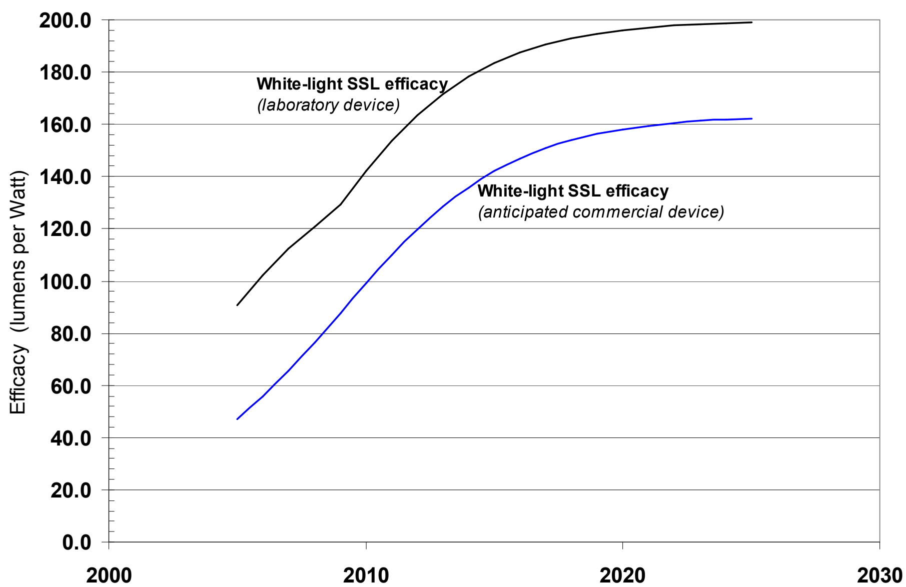
Table 3-25 Installed Base of Lighting Power Density for Conventional Technologies

Characteristics of Commercial Buildings	Units	Calendar Year				
		2005	2010	2015	2020	2025
Conventional Technology Performance	Watts/ft²	1.50	1.32	1.16	1.02	0.9

Considering the anticipated growth in demand for lighting over the next two decades, this reduction in lighting power density translates into about 20% lighting energy savings by 2025 (or approximately 2.0 quads of primary energy consumption savings). However, not all of these savings will be directly attributable to the Lighting subprogram – those savings driven by codes and standards such as ASHRAE 90.1 and California Title 24 do not qualify as benefits derived from the Lighting subprogram. Experts estimate that approximately one-quarter of the savings in a commercial building will be voluntary, leveraged by Lighting subprogram activities. So, for this reason, an estimated one-half of a quad (technical potential) is projected to be saved in 2025 due to the application of new technologies derived from Lighting R&D.

For solid-state lighting technologies, the performance target is focused on the energy efficiency rating of the device. The unit of performance commonly used when discussing light sources and systems is lumens of light produced per Watt of energy consumed. The technical term for this metric is 'efficacy' measured in lumens per Watt. Several lighting products, including fluorescent lamps and incandescent reflector lamps, are regulated using an efficacy target.

Figure 3-13 Plot of Efficacy Projection for White-Light SSL Laboratory Devices



The efficacy projections for solid-state lighting are generated for laboratory devices because the Lighting portfolio does not have direct influence over commercially offered products. The anticipated rate of performance improvement is shown in the following diagram, with an industry-guided estimate of the commercial device expected.

This projection is translated into point values in the following table, with the five-year target milestones.

Table 3-26 Point Values of Efficacy Projections for White-Light SSL Laboratory Devices

Characteristics	Units	Calendar Year				
		2005	2010	2015	2020	2025
Solid-State Lighting Performance	Lumens/watt	71	142	183	196	199

Based on this estimate of performance improvement and assuming a 3 to 5 year lag between laboratory and commercialization, a MARKAL model simulation[34] of the lighting market estimated that the energy savings potential of solid-state lighting, calculated to 2040, would be in excess of 2.6 quads. In terms of power density, an efficacy of 160 lm/W will effectively reduce the power density of a typical commercial office space down to 0.6 watts per square foot. To achieve these savings, the lighting portfolio must continue to emphasize improving the efficiency of SSL technologies, while working through codes and standards and market transformation programs to promote market adoption.

It is important to note that when looking at this efficacy graph, in the last eight years of the Lighting subprogram, the rate of improvements in efficacy begins to decrease. There are two reasons for this projection, first, scientists project that 200 lumens per Watt is approximately the technical maximum that can realistically be achieved, and, as with other technology evolution curves, this upper limit is reached asymptotically. Secondly, once efficacy levels are achieved in the laboratory as high as 160 and 180 lumens per watt, the emphasis of the Lighting subprogram will be to improve manufacturing and production capabilities. When these efficiency levels that are 50% better than fluorescent lamps are available in the laboratory, the focus of the research will shift toward lowering the manufacturing cost and improving production quality (reducing waste), to have an overall effect of reducing the retail price in the lighting market. Thus, due to science approaching the realistic upper limit of the technology and the shift of emphasis from efficacy improvements to cost reduction, the efficacy curve starts to slow down in the final eight years of the program. The activities in these final eight years are critical to achieving the energy savings potential of solid-state lighting.

[34] The MARKet ALlocation model, or MARKAL, is a partial equilibrium, bottom-up energy system technology optimization model employing perfect foresight and solved using linear programming. Numerous model variants expand the core model to allow for demand response to price.

3.3.6 Lighting Market Challenges and Barriers

The Lighting portfolio focuses primarily on barriers associated with technical issues. Market barriers are not part of the portfolio's core mandate, as these activities are implemented by other initiatives within Building Technologies such as Appliances and Emerging Technologies and Energy Star. For this reason, the focus of the conventional technologies activities is shifting away from activities that are ready for commercialization and instead focusing on tasks that are more in line with lighting technology research and development.

3.3.7 Lighting Technical (Non-Market) Challenges/Barriers

For conventional technologies, there are three barriers which the Lighting portfolio is working to address and for solid-state lighting technologies, there are six barriers which the Lighting subprogram is working to address, as shown in the table below.

Table 3-27 Lighting Technical Barriers

Barrier	Title	Description	Target
A	Efficacious Light Sources	The efficacy of all conventional lighting technologies could be higher. Need to develop more efficient sources across all types of conventional lighting technologies (e.g., increase operating temperature of incandescent filaments without shortening operating life, improve phosphor efficiency for fluorescent lamps without decreasing color quality, increase operating efficacy and color of HID lamps).	Conventional Lighting
B	Efficient Fixtures and Controls	The market is aware of lighting controls, but the level of adoption is just a few percent of total sales. Dimming fluorescent ballasts are three times more expensive than non-dimming electronic ballasts and system installation and commissioning costs are high. The technology has achieved commercialization status, and the main market barriers are now primarily centered on deployment rather than R&D.	Conventional Lighting
C	Human Factors	Through better knowledge of how humans perceive and use light, energy savings can be captured. Studies on scotopic lighting have demonstrated the human's ability to work and see better under lower light levels with enhanced scotopic spectra. The technology and research addressing this barrier is near completion. The barriers are now primarily market and deployment related.	Conventional Lighting

Barrier	Title	Description	Target
D	Quantum Efficiency	Quantum efficiency represents the capability of SSL devices to convert electrons into photons. It is governed by the internal and external quantum efficiency of the materials in the device. The internal quantum efficiency assesses a material's ability to convert electron-hole pairs into photon emissions. The external quantum efficiency measures the amount of light that leaves the semiconductor device and is available for collection and use. Both internal and external quantum efficiencies need to be increased. Improvements are possible in through a combination of materials research, photometric modeling and other techniques. *Degree of Difficulty: Very High. Researchers estimate that to improve quantum efficiency will require multiple approaches and perhaps even a fundamental breakthrough.*	Solid-State Lighting
E	Lifetime	To be acceptable to the end-user, white SSL devices should have an operating life approaching 50,000 hours, which is considerably longer than conventional sources. Improvements are possible through advancing scientific understanding of the role of impurities, defects, crystal structure and other factors closely related to materials systems choices. *Degree of Difficulty: High. It may require at least two technical approaches in order to achieve an operating life that exceeds that of fluorescent and high-intensity discharge sources.*	Solid-State Lighting
F	Stability	Stability and control activities address the quality and stability of the white-light emission over time. White-light can be created either by blending several wavelengths of colored light or by down-converting blue or ultraviolet light with a phosphor. Using either the phosphor-converting LED or the RGB approach for white-light production presents special system integration challenges for inorganic devices. Phosphorescent monomer OLEDs may be more uniform in color over time, but	Solid-State Lighting

Barrier	Title	Description	Target
		may be more elusive to discover. Basic material properties and semiconductor physics directly impact photon wavelength, emission bandwidth and ultimately, light color. *Degree of Difficulty: Very High. The production of white-light at the highest efficacies involves blending together discrete sources (e.g., red, green, blue, and orange). However, each of these sources has unique material properties, and therefore its own performance degradation curves.*	
G	Packaging	The first products to hit the market, whether new fixtures or replacements, will have to meet high quality standards to persuade the market that the technology is worth purchasing again. And, if SSL products can't be integrated into lighting products that consumers want, market penetration will always be low. Packaging research focuses on SSL device packages that seal out moisture and oxygen, manage heat transfer, and protect optical material from UV degradation. *Degree of Difficulty: Moderate. Will require a technological break-through. Widely recognized as important.*	Solid-State Lighting
H	Infrastructure	Infrastructure pertains to the installation, maintenance and supporting systems (power conversion) for the SSL products. Fixtures can be envisioned as permanent, much like stairs, plugs and other fixtures in a home or building. These and other unique features such as color shifting and dimming controls will require innovation and infrastructure development. This research activity also includes health and safety issues, information dissemination and training. *Degree of Difficulty: Low. Once the deployment phase starts, infrastructure activities will be initiated.*	Solid-State Lighting
I	Cost Reduction	High first-costs of lighting products extend payback periods and reduce the market penetration potential of new technologies. Consumers are less willing to invest in a new	Solid-State Lighting

Barrier	Title	Description	Target
		technology if it's significantly more expensive than their current, adequate system. To compete in general illumination applications, cost will be an important barrier to address. Lowering the cost of highly efficient SSL sources will enable the realization of energy savings. Cost reduction activities concentrate on materials, and methods and techniques to reduce light production costs through the aggressive development of suitable manufacturing and production technologies. *Degree of Difficulty: High. If SSL devices remain at more than ten dollars per kilolumen (first-cost), their market penetration will be limited to niche applications.*	

3.3.8 Lighting Strategies for Overcoming Barriers/Challenges

The approach of the Lighting portfolio is bifurcated into activities relating to conventional lighting and those relating to solid-state lighting. This breakdown is necessary due to the stage of technical maturity of each of the respective R&D areas, where conventional technologies have more emphasis on development and solid-state technologies have more emphasis on research.

For conventional lighting technologies, R&D activities encompass a broad portfolio of projects, including light sources, fixtures, distribution and controls, and human factors. Some of these activities are now entering the phase where they are ready for Building Integration actions, commercialization and market transformation, and will be transitioned out of the Lighting portfolio over the next two years. The strategy of the Lighting subprogram in the coming two years will include a shift of emphasis to research, with a strong science and engineering focus. The strategy should better align with industry priorities, by not creating redundant systems that compete with already commercialized products, but by plugging missing technical elements that would drive the market to higher efficiency, better performing sources and devices.

The technical objective for the Lighting subprogram states that 'by 2025, develop and demonstrate energy-efficient, high-quality, long-lasting lighting technologies that have the technical capability of illuminating our buildings using 50% less electricity than lighting technologies in 2005.' This objective is broad-based, and encompasses activities in both conventional technology areas as well as in solid-state. The three current components of the strategy for conventional lighting technologies are:

- Light source technology (e.g., incandescent, fluorescent, high-intensity discharge)
- Lighting controls and fixtures (note: plan to transition most projects to other BT program areas to increase market penetration by end of FY 2006)
- Spectrally enhanced light sources and other human-factor related research (note: plan to transition most projects to market transformation program areas by end of FY 2006)

Projects in two of the conventional lighting strategy components are ready for commercialization and will gradually transition to Building Integration subprograms and/or market transformation and emerging technology program areas. In doing so, more energy savings benefits will be captured, as these projects capitalize on the technology and facilitate market adoption.

For solid-state lighting, the program is structured around one guiding strategic objective – energy-efficiency. This objective, while one that is of interest to industry, is unlikely to become a core principle of an industry-led R&D program. Market drivers impacting industry place emphasis on other value adding propositions such as lifetime, light quality, manufacturing technologies, controls strategies and so on.

In order to develop technologies with the technical potential to reduce energy consumption by 50% over 2005 technologies, solid-state lighting will need to increase its efficacy (lumens per Watt) to more than 160 lumens per Watt. Typical fluorescent lighting systems today operate at approximately 80 lumens per Watt, and incandescent systems (depending on the fixture) can range from 5 to 25 lumens per Watt. Thus, the strategy of improving the efficacy of SSL will result in considerable life-cycle benefit to consumers, once the technology is available and commercialized. The solid-state lighting performance target was developed in consultation with industry and technical experts. The projection is for solid-state lighting devices to exceed 160 lumens per Watt.

Table 3-28 Lighting Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Efficacious Light Sources	Focus on HID light sources.
B	Efficient Fixtures and Controls	Transition appropriate projects here to focus on transformation activities through appliances and emerging technologies and Energy Star.
C	Human Factors	These activities should be transitioned out of Lighting R&D and coordinated instead with other program areas to focus on market transformation activities.
D	Quantum Efficiency	The focus of research in this area is to efficiently produce and extract photons from devices with minimum heat production
E	Lifetime	The focus of research in this area is to understand degradation & failure mechanisms to extend practical lifetimes of devices

Barrier	Title	Strategy
		to make them as life cycle cost beneficial as possible.
F	Stability	The focus of research in this area is to improve basic material properties & processes that impact the color & control of the light emitted from the devices.
G	Packaging	The focus of development activities in this area are to design devices into practical packages that satisfy marketing and manufacturing goals, UV tolerance and seal out water and oxygen contamination of the products.
H	Infrastructure	The focus of development activities in this area are to look carefully at the marketing, sales, installation and support associated with the introduction of new solid-state light sources and fixtures.
I	Cost Reduction	The focus of development activities in this area is to reduce the production costs to enable manufacturers to compete with existing, inefficient light sources including fluorescent.

3.3.9 Lighting Tasks

The Lighting subprogram has nine specific tasks which it is managing to address the nine market barriers.

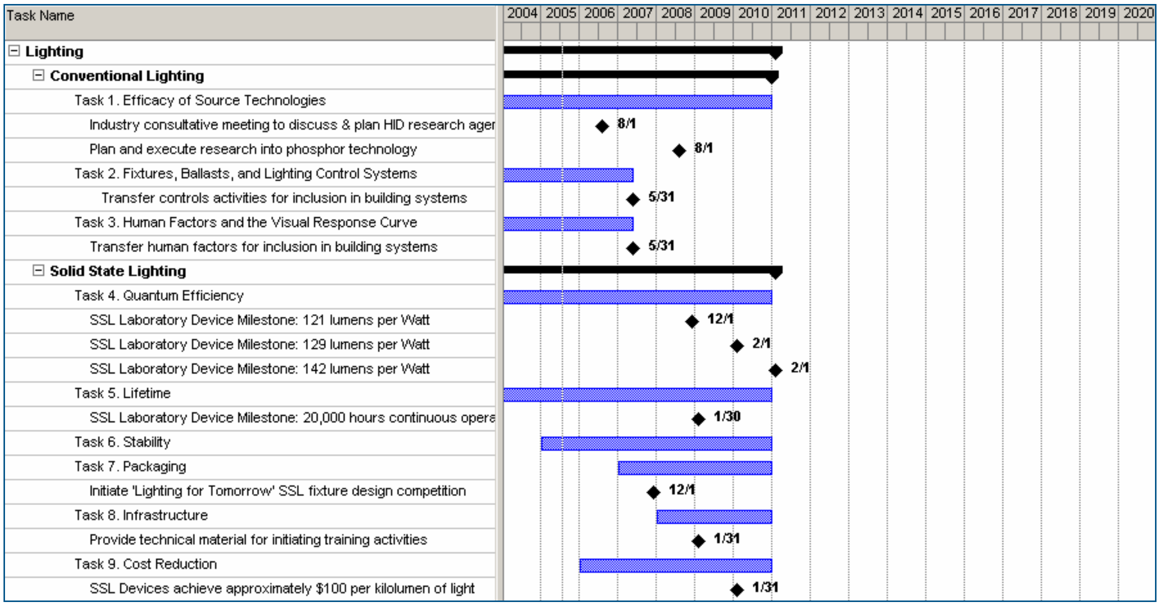
Table 3-29 Lighting Research and Development Tasks

Task	Title	Duration	Barriers
1	Efficacy of Source Technologies	8 years	A. Efficacious Light Sources
2	Fixtures, Ballasts, and Lighting Control Systems	4 ½ years	B. Efficient Fixtures and Controls
3	Human Factors and the Visual Response Curve	4 ½ years	C. Human Factors
4	Quantum Efficiency	8 years	D. Quantum Efficiency
5	Lifetime	8 years	E. Lifetime
6	Stability	6 years	F. Stability
7	Packaging	4 years	G. Packaging
8	Infrastructure	3 years	H. Infrastructure
9	Cost Reduction	5 years	I. Cost Reduction

3.3.10 Lighting Milestones & Decision Points

For each project/task activity identified in the previous section, a Gantt chart has been prepared to show the critical milestones, off-ramps and transfer points for the Lighting subprogram. Each of the nine bars appearing in the Gantt chart is discussed in detail following the chart and key.

Figure 3-14 Lighting Gantt Chart



3.4 HVAC and Water Heating

Table 3-30 HVAC and Water Heating Summary

Start date	1980s
Target market(s)	Residential and Commercial Buildings
Accomplishments to date	• Initial development and ongoing improvement/enhancement of the DOE Heat Pump Design Model • Establishment of the total equivalent warming impact as a measure of global warming impacts of heating, refrigeration, and air-conditioning systems • First publication of laboratory measured vapor compression system performance for R-134a, R-32, R-125, and R-143a • Development and commercialization of an aerosol duct sealing technique • Creation of an ASHRAE Standard for estimating efficiencies of thermal distribution systems • Development of a “drop in” Heat Pump Water Heater (HPWH) • Development and patenting of a low-cost immersed condenser HPWH concept
Current activities	• Support field testing and evaluation of existing equipment in BA home to assess their feasibility in ZEH environments • Begin design, fabrication, and initial proof-of-concept prototype testing of new HVAC system concepts optimized for the ZEH environment • Create conceptual designs of the most attractive integrated water heating appliance concepts, followed by the creation of

	prototype hardware for testing and evaluation
Future directions	• HVAC systems that meet the needs of a ZEH in various climate zones, including major reductions in energy consumption and peak demand, as well as excellent comfort control • Integrated appliances that combine space conditioning and water heating or capture waste heat for use in water heating
Projected end date(s)	2020
Expected technology commercialization dates	2010 to 2020

3.4.1 External Assessment and HVAC Market Overview

Space conditioning equipment for residential and commercial buildings consumes approximately 38% of the total energy used in buildings and electric cooling is an important contributor to summer peak electricity demand.[35]

In residential buildings, space heating is the dominant component of energy consumption, accounting for 31.7% (versus 12.4% for space cooling). Natural gas-fired furnaces and boilers are by far the most common heating systems; fuel-oil based systems and hydronic systems each account for less than 15% of heating energy consumption.[36]

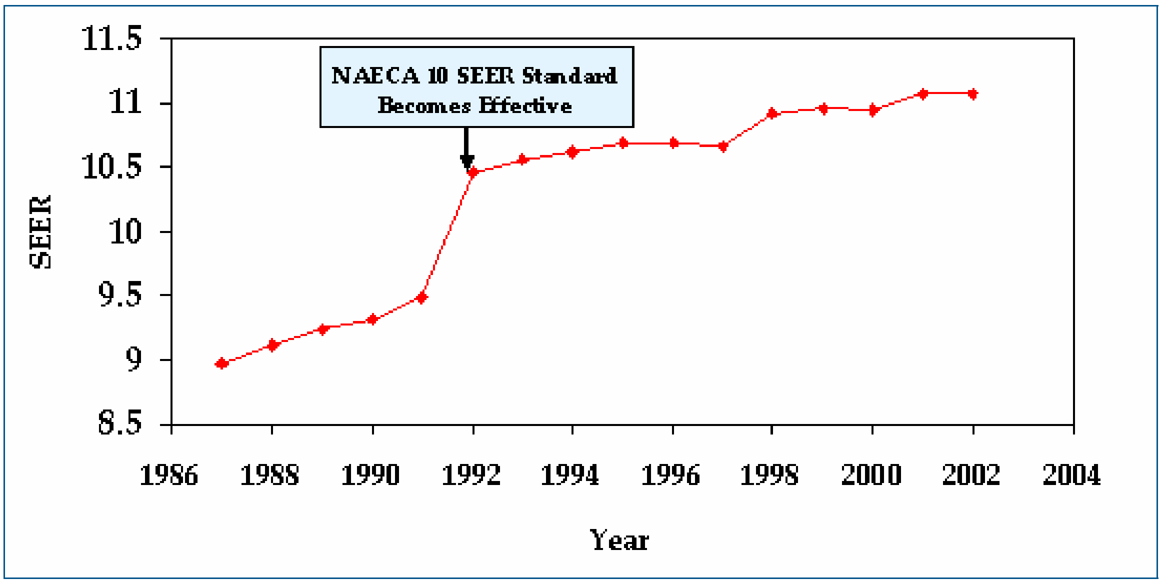
Water heating constitutes the next largest element of residential energy consumption after space conditioning, accounting for 12.7% of primary energy consumption. In commercial buildings, HVAC is the single largest component of primary energy consumption, accounting for 31.6% (14.1 % for heating, 11.7% for cooling, and 5.8% for ventilation), while water heating is substantially smaller, at 6.5%[37], although it is a significant end-use in some building types, such as hotels, hospitals, and restaurant.

The majority of space conditioning equipment sold in the U.S. (approximately 70-80% in most years) meets the minimum efficiency standard level mandated by DOE regulations. In recent years, the HVAC industry has seen only modest improvements in equipment efficiency, largely driven by the efficiency standards. The 13 SEER minimum standard scheduled to take effect in 2006 will cause another large step increase in equipment efficiency. However, it is likely, at least in the next few years that shipments of units with SEER greater than 13 will amount to less than 10% of the market, and most of these will probably be at 14 SEER. Premium HVAC systems sold in the U.S. will typically incorporate features that are valued by the customer, such as reduced noise and better fit and finish, but have little or no impact on efficiency.

[35] BED
[36] Estimated by TIAX, LLC, 2002.
[37] BED

The challenges to selling high efficiency water heating are even greater than for HVAC. Unlike white goods or even HVAC, there are few if any premium features of a water heater (e.g. comfort, aesthetics, image, enhanced functionality) that can be combined with efficiency to up sell high efficiency products. Furthermore, most replacements are emergency replacement sales where immediate availability is essential and upgrading to more energy efficient units is not feasible. Finally, the relatively small energy costs of water heating to individual consumers can make it difficult to justify a higher first cost product. Electric heat pump water heaters (HPWH) and condensing gas-fired water heaters offer significant energy savings over conventional products, but have very high price premiums and have therefore achieved a very limited market share. For example, of the 4 to 5 million residential electric water heaters sold annually in the U.S., only a few thousand are heat pump water heaters, whose efficiency can be more than double that of conventional units.

Figure 3-15 Shipment Weighted SEER of Unitary Air Conditioner Shipments[38]



The basic design concept for both vapor-compression HVAC systems and water heaters has changed very little in decades. These products look much the same today as they did 20 years ago. Because incremental improvements and minimum efficiency standards (e.g., NAECA, EPACT, ASHRAE 90.1) have captured much of the "low-hanging fruit" available for further efficiency gains, new design approaches are necessary.

The primary focus of HVAC and Water Heating R&D within the Emerging Technologies program is to address the critical needs of the ZEH effort. Building America targets dramatic reductions in energy consumption in single family homes, leading to net-zero energy homes by 2020. Cost effective, highly efficient space conditioning and water heating systems are critical to reaching this goal. Consequently, the HVAC & Water Heating program will work closely with the Residential Integration subprogram to ensure

[38] *ARI Statistical Profile*, Air Conditioning and Refrigeration Institute, October 7, 2004.

that R&D is closely aligned with evolving needs and those new technologies can be rapidly field-tested in a real world environment and transitioned to market in cooperation with Building America industry partners.

In addition, over the next several years, the equipment and performance needs of HVAC and water heating systems for commercial ZEBs will become better defined, through the efforts of the commercial integration subprogram. In subsequent years, the HVAC and Water Heating R&D activity will work closely with the commercial buildings team to understand those needs and help develop and test potential solutions. Therefore, while the immediate focus of our R&D will be on residential ZEH needs, we expect to devote additional resources to commercial ZEB needs in the future.

Achieving the residential ZEB goals will require, "development of space cooling and heating equipment that is at least 30-50 percent more efficient than current technology". To meet this objective, smaller, more efficient systems must be developed."[39] The focus will be on system energy consumption, rather than simply EER or SEER, which do not capture the impacts of the entire HVAC system, and the baseline for comparison will be the International Energy Conservation Code (IECC) 2003 benchmark. HVAC equipment will also need to be designed specifically to meet ZEH building loads, which will be quite different in magnitude and relative proportions (e.g. cooling/heating/dehumidification/ domestic hot water) than those of current buildings. Specifically, humidity control in a ZEB is very challenging using conventional HVAC equipment.

Any new high efficiency water heating product must have very modest price premiums over conventional units, while offering substantial energy savings. In order to achieve the goals set out by the ZEB program for 2025, water heating energy consumption from non-renewable sources will need to decrease by approximately 80 percent.[3]

This MYPP also recognizes that the ZEH technical goal can largely be achieved for some regions of the country, and for some building types, using commercially available technology, but at an unacceptable cost. Reaching the goal with technologies that show promise of becoming affordable is therefore critical. To achieve the economies of scale necessary to produce economical equipment, manufacturers need volumes far greater than the ZEH market can provide. Therefore, a viable ZEH strategy must address equipment that can, in the long term at least, also be part of the broad equipment replacement and new construction market. Therefore, research should address the needs of the ZEH but should also consider the needs of the large base of existing houses, in order to provide a sufficiently large market to warrant the attention of equipment manufacturers. In addition, because new construction adds only a few percent (~1-3%) to the building stock each year, thus accounting for only a very small portion of energy consumption, it is important to address energy savings opportunities in existing buildings, not only ZEBs.

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[39] *Zero Energy Homes' Opportunities for Energy Savings: Defining the Technology Pathways through Optimization Analysis*, U.S. Department of Energy, Building Technologies Program. Prepared by Navigant Consulting, Inc., October 2003. Hereafter, ZEH.

High efficiency HVAC systems are available commercially today, but their market penetration is extremely limited, due primarily to their high initial costs. For example, less than 5 percent of residential unitary air conditioner shipments have SEER ratings above 14, compared to that national minimum of 10 (which will rise to 13 in 2006). Such high efficiency systems have other drawbacks as well, including their large size and concerns about humidity control. New product designs and system approaches will be needed to overcome these limitations.

Most prior efforts at improving markets for efficient water heater technology were focused on efficient methods for generating hot water from purchased energy, or using renewable resources such as solar. Heat pump water heaters (HPWHs) produced by three small U.S. manufacturers and condensing gas water heaters are technologies which deliver more efficient water heating. Largely due to the high initial cost, as well as previous field installation issues with first generation products, markets for these technologies remains very limited, and technological breakthroughs that would dramatically lower these costs seem unlikely, so new approaches must be sought.

3.4.2 Internal Assessment and HVAC History

DOE has conducted research efforts to improve the efficiency of space conditioning equipment for buildings for over two decades. Significant and largely enabling technical accomplishments include initial development and ongoing improvement/enhancement of the DOE Heat Pump Design Model (HPDM), establishment of the total equivalent warming impact (TEWI) as a measure of global warming impacts of heating, refrigeration, and air-conditioning systems, first publication of laboratory measured vapor compression system performance data for R-134a, R-32, R-125, and R-143a (constituents of the primary HFC alternatives to CFC and HCFC refrigerants), and development of the Annual Cycle Energy System. Many small to medium size unitary HVAC manufacturers use the DOE HPDM as their primary computer-based new product design aid.

Over the past decade DOE research efforts have also advanced the understanding of energy use in residential thermal distribution systems. This work has focused on forced air system duct losses but has also included consideration of hydronic systems. Some highlights are: development and commercialization of an aerosol duct sealing technique, creation of an ASHRAE Standard for estimating efficiencies of thermal distribution systems, and improved diagnostic techniques for duct leakage and other air flows.

BT has conducted research efforts to improve the efficiency of electric water heating for many years. Significant recent accomplishments include: the development of a “drop in” heat pump water heater design, which was named 2002 R&D100 award winner, and the development and patenting of a low-cost immersed condenser HPWH concept which is expected to be field-tested soon.

The substantial energy consumption associated with cooling systems, and their major contribution to peak electricity demand, suggest a role for the federal government in supporting HVAC R&D. Because of the intensely price-competitive nature of the industry, HVAC and water heater manufacturers spend a relatively small percentage of revenues on R&D, typical under two percent. Furthermore, their R&D efforts and limited resources are generally directed to near term product development and engineering needs, leaving little opportunity for long-term R&D of the sort necessary to address ZEH applications, unless the DOE provides guidance and a framework for analyzing ZEH needs. If the DOE provides such guidance, manufacturers are willing to work cooperatively with the DOE to develop solutions to address these needs.

3.4.3 HVAC and Water Heating Approach

The HVAC efforts can be broadly divided into two distinct elements:

- Development of HVAC Equipment and Design Options for the ZEH
- Integrated Water Heating Systems for the ZEH

HVAC Equipment and Design Options for the ZEH

The focus of HVAC R&D efforts will be on system energy consumption, rather than simply EER or SEER, which do not capture the impacts of the entire HVAC system. The baseline for comparison will be the International Energy Conservation Code 2003 benchmark. HVAC equipment will also need to be designed specifically to meet ZEH building loads, which will be quite different in magnitude and relative proportions (e.g. cooling/heating/dehumidification and domestic hot water) than those of current buildings. Specifically, humidity control in a ZEH is very challenging using conventional HVAC equipment, and forced mechanical ventilation may be required to ensure acceptable IEQ in these homes, due to their tight envelopes. Furthermore, different climate zones will likely require different solutions to achieve optimal cost-efficiency tradeoffs.

Although the energy efficiency of HVAC equipment has increased in recent years, new approaches, including radically new ideas, are needed to continue this trend. The dramatic reductions in HVAC energy consumption necessary to support the ZEB goals require a systems-oriented analysis approach that characterizes each element of energy consumption, identifies alternatives, and determines the most cost-effective combination of options. Therefore, the first task in this effort will involve system characterizations, identification of necessary upgrades to analysis tools, and an assessment of cost and performance of alternative solutions. The following technologies are elements of possible solutions identified in cooperation with the Building America team, but the initial evaluation may substantially alter these plans:

- Enhanced ground-coupled unitary HVAC systems based on selective water sorbent (SWS) technology for outdoor heat exchanger.
- Distributed space conditioning based on ductless multi-split technology with advanced zone control tied to occupancy sensors, or “point source” systems which include multiple fractional tonnage through-the-wall HVAC systems with separate ventilation and room-by-room control.
- Stand-alone, direct expansion dehumidification systems with energy recovery ventilation and possibly hot water preheating

This effort is specifically targeted to achieving demonstration of 2 to 3 design concepts that have the long term potential to reduce annual HVAC energy consumption by 50% in new residential buildings (without taking into account building load reductions from other factors), relative to Building America Benchmarks, with an estimated simple payback period of 3 years or less. The design concepts must also address other critical Building America needs such as humidity control, uniform comfort, and indoor air quality. If design concepts which combine space conditioning and water heating are proposed, energy consumption payback period targets will be calculated relative to Building America Benchmark totals for both functions.

Integrated Water Heating Systems for the ZEH
Integrated systems that perform other functions in addition to water heating will become increasingly valuable in ZEH design. Beyond water heating energy savings, such products would provide other benefits or reduce energy costs in other ways (e.g. by providing dehumidification, or by combining functions or using waste heat from other appliances). Systems which combine water heating with other functions (e.g. space conditioning) and/or recover waste heat from other appliances or Combined Heat and Power (CHP) systems, will also be evaluated and possibly developed under this plan.

The value of integrated systems is evident whenever there is surplus or exhaust heat (or cooling) from an appliance that can be provided to others thereby boosting the overall efficiency of the combination of appliances. As a simple example, exhaust air from a domestic clothes dryer could be filtered and ducted to provide heat and humidification to a home during the winter. The end result is an appliance that performs several functions (drying, humidification and heating) that would otherwise require several individual appliances. In a more complex approach, the condenser heat from a domestic refrigerator could be captured and used to provide domestic hot water. Appliances such as air conditioners, heat pumps, refrigerators and dehumidifiers that use compressors and therefore provide heating and cooling at the same time, provide opportunities as integrated appliances that perform dual functions.

As a first step, a scoping study will be completed in FY 2006, and will include:

- Characterization of current market for integrated appliances;
- Review of previous R&D on integrated water heating appliances;
- Conceptualization of various integrated appliance options, including systems that capture waste-heat from other appliances (or drain water), as well as combination heating appliance approaches. The concept of an integrated heat pump with selective water sorbent currently being tested at ORNL will be one of several ideas considered;
- Identification of engineering approaches for combination heating appliances, estimates of waste heat available from various appliances, and coincidence with water heating needs;
- Preliminary engineering concepts for transporting and storing waste heat from other sources;
- Energy and peak demand savings estimates;

- Assessment of key market barriers (including lack of test procedures); and
- Identification of most promising opportunities (Go/No-go decision).

If the scoping study suggests attractive product development opportunities, future activities would involve conceptual design of the most attractive approaches, prototype development, and testing and evaluation (followed by a Go/No-go decision).

Various concepts for high efficiency water heating exist today and have been the subject of considerable R&D in recent years. They include heat pump water heaters, condensing gas-fired water heaters, tankless water heaters and solar water heating. All have proven cost-prohibitive despite substantial cost reduction efforts. We are not aware of any likely breakthroughs in these technologies that could dramatically reduce their costs, but remain open to the possibility that such breakthroughs may become possible due to advances in new materials, manufacturing technologies, electronics, or technology transfer from other industries or products. We will continue to monitor potential concepts, such as solar water heating, and remain open to exploring new pathways to achieving dramatic cost reductions if they become apparent.

3.4.4 HVAC Strategic Goals

Achieving the residential ZEB goals will require the development of space cooling and heating equipment that reduces energy consumption by 50 percent relative to the International Energy Conservation Code 2003 benchmark.[40] Our goal is to develop technologies with the long-term potential to meet this goal with an estimated simple payback period no greater than 3 years. For water heating, our target payback period is 5 years.

3.4.5 HVAC and Water Heating Performance Goals

Table 3-31 HVAC and Water Heating Performance Goals

Characteristics	Units	Year		
		2005	2010	2015
Residential Annual HVAC Energy Consumption Reduction vs. 2003 Baseline (with simple payback ≤ 3 years)	%	Baseline	50	-
Commercial Annual HVAC Energy Consumption Reduction vs. 2003 Baseline	%	Baseline	-	80
Residential Annual Water Heating Energy Consumption Reduction vs. 2003 Baseline (with simple payback ≤ 5 years)	%	Baseline	50	80

The HVAC & Water Heating R&D activity is fully aligned with the strategic goals of the BT program, specifically by developing technologies, products and solutions that support the ZEB effort, initially focusing on residential buildings, but with the expectation of

[40] ZEH

addressing commercial ZEB needs in the long term. In order to ensure that our R&D activities remain aligned with these strategic goals as they evolve, we will work closely with the residential and commercial integration subprograms, through periodic meetings, research collaboration and by participating in their program review meetings.

The long-term measure for the HVAC and Water Heating subprogram is the number of HVAC technology packages designed for new residential buildings. These technology packages must demonstrate through field or laboratory testing the potential to reduce annual HVAC energy consumption by 50% in new residential buildings (without taking into account building load reductions from other factors), relative to Building America benchmarks with an estimated simple payback period of 3 years or less. (5 years for water heating). The performance metric targets for the next five years are in Table 3-32.

Table 3-32 HVAC and Water Heating Performance Metrics

Characteristics	Units	Year		
		2006	2008	2010
HVAC Technology Packages for New Residential Buildings	Number	1 (conceptual design)	2 (field testing)	2 (commercialized)
Integrated Water Heating Appliances	Number	1 (conceptual design)	2 (field testing)	1 (commercialized)

The design concepts must also address other critical Building America needs such as humidity control, uniform comfort, and indoor environmental quality (IEQ). Several different design approaches will be necessary for optimal performance in different climate zones and building types. If design concepts which combine space conditioning and water heating are proposed, the energy consumption and payback period targets will be calculated relative to Building America benchmark totals for both functions.

3.4.6 HVAC Market Challenges and Barriers

The market barriers to meeting the HVAC strategic goal and performance goals are described in the following table.

Table 3-33 HVAC and Water Heating Market Challenges and Barriers

Barrier	Title	Description	Target
A	Affordability	The ZEH strategy requires development of much more affordable systems. Many high efficiency HVAC and water heating products and systems are already available in the marketplace, but are far too expensive for widespread adoption. Any new technology or system developed must be cost competitive with today's technologies.	High efficiency systems with simple payback of 3 years (HVAC) - 5 years (water heating)
B	Market Acceptance	Current water heaters are simple to install. New products need to be easily installed and maintained without necessitating substantial additional training for installers or requiring additional trades personnel. Current products are very reliable, but HPWHs have suffered from poor reliability, leading to a poor market image. Most water heater sales are replacements where immediate availability is essential and "up-selling" is uncommon. Coupled with the commodity nature of the product, this limits the potential for advanced products.	Reliability and maintainability equivalent to existing products. Installation similar to current practice with limited additional training and no additional personnel

3.4.7 HVAC Technical (Non-Market) Challenges/Barriers

The technical barriers to meeting the HVAC strategic goal and performance goals are described in the following table.

Table 3-34 HVAC and Water Heating Technical Challenges/Barriers

Barrier	Title	Description	Target
C	Achieving High Efficiency in Low Capacity HVAC Systems	Substantial efforts have been made to raise the efficiency of 2-5 ton heat pumps and air conditioners. As system capacity is reduced, certain losses (e.g. clearance volume flow in compressors, high-to-low pressure section leakage in reversing valves) tend to become a larger percentage of total capacity. New developments are needed to achieve high efficiency in	High efficiency systems in the capacity range of 0.5 – 1.5 tons are needed.

Barrier	Title	Description	Target
		small systems.	
D	Sustained Performance	Systems must be designed to sustain their initial efficiency throughout the life of the equipment or notify users when performance deteriorates so corrective action may be taken.	Systems should continuously operate within 10% of initial efficiency levels and/or notify users of significant deviations
E	System Efficiency	The benefits of efficient HVAC systems can be realized only if system performance is improved significantly. Therefore, near-zero-loss systems to distribute heating, cooling, and ventilation must be developed which are cost-effective and simple to install. Furthermore, providing comfort conditioning only when and where it is needed to satisfy occupants requires systems that permit efficient zoning and sensors to optimize indoor air quality and humidity while also minimizing energy consumption.	Current rating methods focus only on the efficiency of the "box", using SEER or EER as a metric. Total energy consumption relative to the IECC benchmark is a more appropriate metric for evaluating system efficiency.
F	Ensuring Comfort and Indoor Environmental Quality (IEQ)	Traditional residential HVAC systems do not provide adequate humidity control under certain conditions (e.g. when sensible cooling loads are low) and do not provide sufficient fresh air ventilation which is necessary to ensure IEQ in tight homes.	Provide comfort and acceptable IEQ that conforms to ASHRAE Standard 62.2 in ZEHs in all climate zones

3.4.8 HVAC Strategies for Overcoming Barriers/Challenges

Table 3-35 HVAC & Water Heating Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Affordability	Designs must use simple, off-the-shelf components that are mass produced, and the concepts will not incorporate other features that raise costs without any energy benefit.
B	Market Acceptance	Concepts will maintain design simplicity, use of conventional components, and ease of installation and maintenance.
C	Achieving High Efficiency in Low Capacity HVAC	New design concepts may incorporate point source cooling systems and small capacity, variable speed compressors such as those used in ductless room air

Barrier	Title	Strategy
	Systems	conditioners.
D	Sustained Performance	Designs will either include integrated fault detection and diagnostic (FDD) systems or should tolerate typical faults such as modest loss of refrigerant charge without significant performance deterioration.
E	System Efficiency	Rather than focusing solely on efficiency at the SEER rating point, as is typically done, new concepts will target part-load efficiency, reduced energy consumption through smart zone control, and approaches such as waste heat recovery that are not easily captured by the SEER metric but that can reduce energy consumption dramatically. For water heating systems, distribution system losses will also be considered.
F	Ensuring Comfort and Indoor Environmental Quality (IEQ)	New HVAC designs will provide integrated dehumidification capable of sufficient latent cooling under all conditions and will also provide low-cost, low loss mechanical ventilation

3.4.9 HVAC and Water Heating Tasks

Meeting the needs of the ZEH program will require new approaches to generating and distributing heating, cooling, and hot water, and meeting the particular needs of ZEH occupants. Planned activities fall broadly into two categories, one addressing HVAC systems and the other addressing water heating. Some integrated appliance concepts may incorporate both functions in a single product or system. Furthermore, as noted previously, the cost optimal solution may be very different in different climate zones.

Many different design concepts will be considered, based on input and discussions with the Building America team. Because we can not yet predict which solutions are likely to prove most promising, our plan begins with comparisons of possible alternatives, leading to several conceptual designs, and then to detailed prototype design, assembly and testing. The designs will ultimately be field tested in Building America homes, which provide an excellent test bed for monitoring real world performance prior to commercialization. It is expected that several different HVAC concepts will be field tested, to address the specific needs of different climate zones.

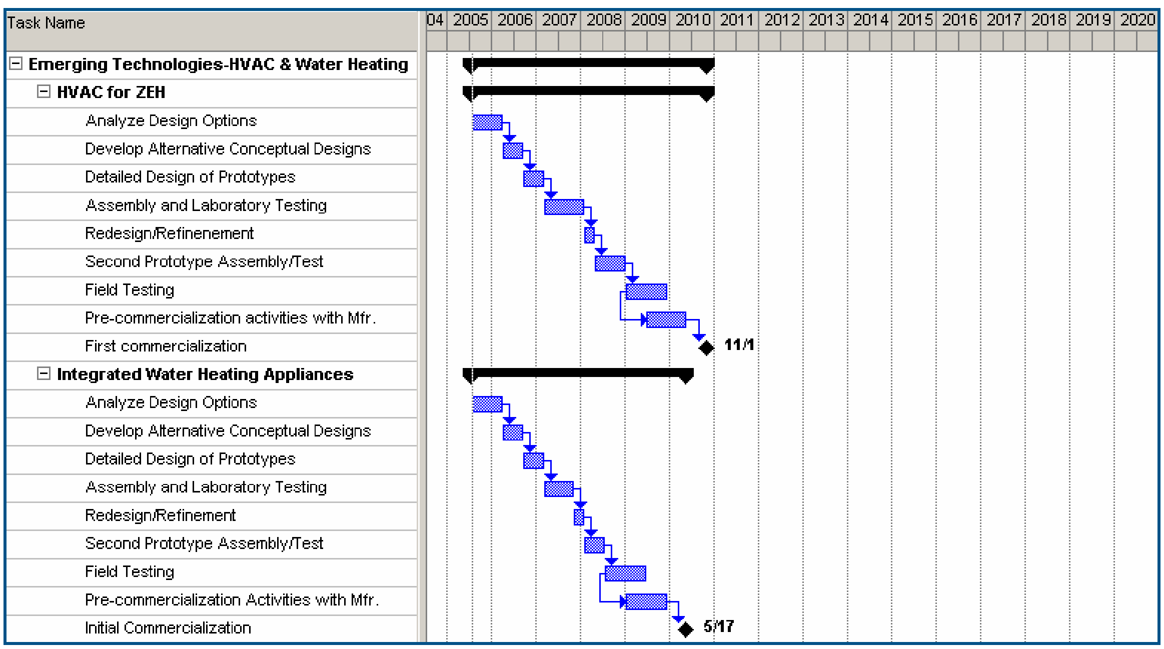
Table 3-36 HVAC and Water Heating Tasks

Task	Title	Duration	Barriers
1	HVAC needs for Zero Energy Homes	20 Quarters	A. Affordability, C. Achieving High Efficiency in Low Capacity HVAC Systems, D. Sustained Performance
2	Integrated Water Heating Appliances	20 Quarters	A. Affordability, B. Market Acceptance, E. System Efficiency
3	Low loss domestic hot water distribution systems	TBD (depends on results of ongoing studies)	A. Affordability E. System Efficiency

3.4.10 HVAC Milestones & Decision Points

The Gantt chart below shows tasks within the two primary activities planned for the HVAC and Water Heating R&D program. An additional sub-activity, addressing needs for low loss hot water distribution systems, may be added in subsequent years, if appropriate R&D needs are identified as a result of ongoing field studies.

Figure 3-16 HVAC & Water Heating Gantt Chart



3.5 Envelope

Table 3-37 Envelope Summary

Start date	1980
Target market(s)	Subprogram focuses on new and existing residential buildings, but some aspects address new and existing commercial buildings.
Accomplishments to date	1. Developed and demonstrated energy savings benefits of dark colored metal roofing materials that are highly reflective. 2. Worked with industry to develop second and third generation of foam insulation materials that were more energy efficient and less costly. 3. Devised manufacturing methods to dramatically reduce the cost of vacuum insulation materials. 4. Developed methodology and tool (WUFI) to assess potential for moisture related damage and the onset of mold problems in order to guide the development of failure resistant energy efficient envelope systems. 5. Developed and produced consumer information and software to help homeowners select the proper type and amount of insulation, thereby promoting use of better insulation for building envelopes. 6. Advised the Federal Trade Commission on issues associated with the FTC Insulation Labeling Rule. 7. Through active participation in ASTM and ASHRAE, developed, revised, and launched over 100 standards pertaining to insulation materials and building envelopes. 8. Assisted in the development of DOE vapor control recommendations that were submitted to the International Residential Code.
Current activities	1. Develop Structural Insulated Panel (SIP) wall systems that are highly efficient, thin, and reduce failure risk. 2. Develop, prototype, and test a roof/attic system that provides a more energy efficient building envelope and a better performing home. 3. Develop next generation of insulation materials that are lightweight but include thermal inertia for increased energy efficiency. 4. Develop an array of highly reflective roofing and wall material products using existing cool pigment technologies.

	5. Study the hygrothermal performance of wall systems in the Pacific Northwest. 6. Complete research on ventilating crawlspaces to determine for which climates ventilation improves energy efficiency and reduces envelope moisture failure risk. 7. Develop the necessary standards that guarantee that building envelope material and system selection is fair and objective so that this work can be carried out by the private sector.
Future directions	1. Conduct SIP facer development to address environmental sensitivity of existing technology, develop new foam insulation products that have higher R-values, and develop advanced joining techniques that are less installation sensitive. 2. Develop new types of low density insulations that are more opaque to radiative heat transfer and have thermal inertia. 3. Develop roofing products for cooling dominated climates that are aesthetically pleasing to the consumer but reflect large percentages of solar radiation. 4. Develop new types of wall systems that are inexpensive and are insensitive to moisture ingress. 5. Develop new construction techniques that allow the use of the attic space but allow air distribution systems to be inside the conditioned space. 6. Develop energy efficient slab and basement foundation systems. 7. Develop tools and standards that allow for the appropriate thermal and hygric design of building envelope systems.
Projected end date(s)	1. Next generation SIPs: 2009. 2. Improved low density insulation: 2008. 3. Reflective roofing products: 2007. 4. Exterior insulation systems: 2008. 5. Highly efficient attics: 2015. 6. Energy efficient and moisture tolerant crawlspaces: 2006. 7. Moisture design standard: 2006. 8. Required standards for industry adoption of moisture testing: 2010.
Expected technology	1. Next generation SIPs: 2009. 2. Improved low density insulation: 2008.

commercialization dates	3. Reflective roofing products: 2004-2009. 4. Exterior insulation systems: 2005-2007.

3.5.1 External Assessment and Envelope Market Overview

The Building Technology Program's long range goal of developing ZEB by 2025 will require more cost effective, durable and efficient building envelopes. To make ZEB affordable, efforts to reduce the energy required for the building are a necessary complement to efforts to reduce the cost of renewable, on-site power. Forty percent of the primary energy used in a residence is spent on space heating and cooling.[41] Reducing envelope energy consumption will significantly facilitate attainment of a practical ZEB since a significant amount of space heating and cooling energy is lost through inefficient envelopes. The importance of the Building Envelope subprogram has been recognized by the Building Integration subprogram, as exemplified by the ambitious envelope targets in the Building America list of optimization-critical component needs.[42]

3.5.2 Internal Assessment and Envelope History

The appropriate use of insulation and building envelope systems hinges on the development and utilization of standards. The non-commercial and unbiased contributions of DOE's activity in the standards arena are an appropriate federal role. Enabling industry research through the provision of highly specialized research facilities is also an appropriate federal role because it significantly accelerates the adoption of superior advanced technologies while the major part of the research cost is still born by the industry partners.

3.5.3 Envelope Approach

The Building Envelope subprogram is focused on meeting the building envelope objectives outlined by conducting collaborative R&D with national laboratories, industry partners, standards and professional societies, and universities, including international participation as appropriate.

Develop the Next Generation of Envelope Materials

The program strategy is to create the opportunity for envelopes to contribute to ZEB by advancing a portfolio of new insulation and membrane materials, including the exterior finishes, having residential and commercial application. The needs for new envelope materials have been expressed in a number of roadmaps.[43, 44, 45]

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41 BED

42 ZEH

43 *Building Envelope Technology Roadmap*, U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, May 2001.

44 *Technology Roadmap: Advanced Panelized Construction, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

The major components of strategy are:

- Develop next generation of low density thermal insulation materials.
- Develop reflective exterior wall finishes.
- Develop smart membrane materials with climatically tuned properties.
- Develop thermochromic roofing surfaces using microstructures down to the nanoscale.

Develop the Next Generation of Attic Systems

The goal for the advanced attic systems project is to make attics constructed by 2010 twice as efficient as Building America's regional benchmarks. Attics were selected because practical solutions for constructing an energy efficient attic do not exist and that attic and roofing systems represent a significant percentage of the aggregate residential building component loads.[46, 47] Achieving this ambitious goal will require a well-coordinated collection of technical advances, using an effective collaboration of engineering and scientific resources.[48, 49]

The major components of strategy for attic systems are:

- Develop and regionally optimize the next generation of attic systems (e.g., insulation, ventilation strategy, component location, ducts).
- Investigate new attic structural systems that will allow for automated construction.
- Develop reliable consensus-based rating methods to assess energy efficiency options for roofing systems.

Develop the Advanced Wall Systems

The goal for the advanced wall systems project is to make these systems constructed by 2010 twice as efficient as Building America's regional benchmarks. A market resistance to increased wall thickness has jeopardized opportunities to improve the energy efficiency of this envelope component in many regions. Therefore, advanced materials and systems are needed that deliver significant improvements in energy performance without increasing wall thickness.

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[45] *Technology Roadmap: Energy Efficiency in Existing Homes, Volume Three: Prioritized Action Plan*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.
[46] BED
[47] Anderson, Ren, et all, *Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes*, November 2004, National Renewable Energy Laboratory. Report No. TP-550-36920.
[48] *Building Envelope Technology Roadmap*, U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, May 2001.
[49] *Technology Roadmap: Energy Efficiency in Existing Homes, Volume Three: Prioritized Action Plan*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

The major components of strategy for wall systems are:

- Develop and regionally optimize the advanced wall systems.[50]
- Invent and evaluate new techniques for window/wall interface.

3.5.4 Envelope Strategic Goals

The strategic goals have been defined with consideration of their energy-saving potential toward the ZEB goal and the research gaps noted in a recent Building America/Emerging Technologies planning meeting.[51] These objectives have been organized to address major building envelope systems, promising new material developments, and enabling technologies.

- Develop the Next Generation of Envelope Materials: By 2015, develop and demonstrate innovative materials that either: (1) will have effective thermal performance improved by 50% relative to functionally-comparable components of the Building America regional baseline new construction; or (2) resolve durability-related problems (moisture, termite, structural, etc.) that may increase envelope failure risk.
- Develop the Next Generation of Attic Systems: By 2013, develop advanced attic and technologies for single family residences that reduce the space conditioning requirements attributable to attics by 50% compared to Building America regional baseline new construction at no additional operating cost and no additional envelope failure risk.
- Develop the Advanced Wall Systems: By 2009, develop advanced wall technologies for single family residences that reduce the space conditioning requirements attributable to walls by 30% compared to Building America regional baseline new construction at no additional operating cost and no additional envelope failure risk.

3.5.5 Envelope Performance Goals

The table below lists the performance goals for the Building Envelope subprogram. All performance measurements are relative to historical baselines that have been set as the Building America regional baseline new construction. One important constraint included for many components of strategies is that of "no additional operating cost", which is defined here as the sum of the mortgage-amortized installed cost and the annual energy costs savings. Ensuring the durability of the envelope is also an integral aspect of these targets.

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[50] *Technology Roadmap: Whole House and Building Process Redesign, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.
[51] *Building America Meetings Series: Quarterly All-Teams Planning Meeting Notes*, November 16-18, 2004, U.S. Department of Energy, Building America Program. Washington, DC.

Table 3-38 Envelope Performance Goals

Characteristics	Units	Calendar Year		
		2004 Status	2007 Target	2010 Target
Advanced attic/roof system	R-Value	30	35	Dynamic annual performance equal to conventional R-45
Color reflectivity (applicable to both walls and roofs)	Solar reflectivity	10%	40%[52]	40%[53]
Moisture property measurements	Test methods	Non-uniform	Uniform set of definitions, interlaboratory comparisons underway for 2 methods	Interlaboratory comparisons underway for 3 additional methods.[54]
Accelerated roof surface durability tests	Time	3 years		6 months
Wall insulation	R-Value	10	Dynamic annual performance equal to conventional R-20[55]	Dynamic annual performance equal to conventional R-20[56]
Panelized wall with non-organic faces, suitable for termite-prone regions	R-value	7	Dynamic annual performance equal to conventional R-20[57]	Dynamic annual performance equal to conventional R-20[58]

[52] Durability not yet assured at interim target.
[53] With attractive dark appearance, and with long-term durability of both reflective properties and appearance.
[54] Interlaboratory tests are a critical testing ground used during the development of new standard test methods. Standards are seldom accepted by consensus organizations until the proposed method has been subjected to this form of peer review.
[55] Interim target NOT subject to cost constraints and may not be in commercial production.
[56] Subject to no additional operating cost, within the traditional 3.5-in. wall dimension, with acceptable durability characteristics.
[57] Interim target NOT subject to cost constraints.
[58] Subject to no additional operating cost, within the traditional 3.5-in. wall dimension, with acceptable durability characteristics.

3.5.6 Envelope Market Challenges and Barriers

Building envelope designs and material selections are typically constrained by cost. This is particularly true during new construction when many homes are built on speculation. Even for retrofit applications, improvements that add cost are very difficult to market unless those costs can be recovered through reduced energy bills. Also, the building envelope industry is highly fragmented. It is unlikely that an envelope is constructed with products from a single manufacturer. Often, a building envelope constructed in the field joins elements that have never been combined exactly the same before. The number of potential combinations of components is astronomical. Issues associated with how products perform together are seldom addressed.

Table 3-39 Envelope Market Challenges and Barriers

Barrier	Title	Description
A	First Cost Sensitivities	There is often an economic disconnect between builders and building occupants.[59] Builders are sensitive to first cost and typically receive no benefits from long-term energy performance improvements.
B	Resistance to Change	The building industry is fragmented and diverse, with a strong resistance to change.[60, 61] Industry rules-of-thumb often take precedence over technical recommendations based on extensive building envelope research.[62]
C	Local Code Variability	Local building codes vary greatly, with thousands of code jurisdictions in the U.S. Although there has been great progress in bringing the code bodies together on the national level, local codes for residential construction and, more importantly, code enforcement are less uniform. In many locations, only the electrical system is inspected. In others, outdated codes preclude the application of recent advances in building science.

[59] *High-Performance Commercial Buildings: A Technology Roadmap*, U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, October 2000.

[60] *Technology Roadmap: Information Technology to Accelerate and Streamline Home Building, Year One Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, June 2002.

[61] *High-Performance Commercial Buildings: A Technology Roadmap*, U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, October 2000.

[62] *Technology Roadmap: Whole House and Building Process Redesign, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.

3.5.7 Envelope Technical (Non-Market) Challenges and Barriers

Table 3-40 Envelope Technical Challenges/Barriers

Barrier	Title	Description
D	Thermal Performance versus Durability Performance	All materials and systems must meet both thermal and durability performance requirements. For example, reflective paint pigments must not only provide the desired radiative properties, but must also be colorfast over long periods of time and must resist wear due to weather exposure.
E	Unknown Interactions	Understanding of the physical interactions between building components and systems is incomplete. For example, early efforts to reduce infiltration often led to moisture problems.[63]
F	Material Developments	Building industry practices are relatively rigid, so that material developments are necessary to provide certain desirable properties, such as increased heat capacity, within the limitations of typical light frame building practices.
G	Large Scale Facility Requirements	Large scale test apparatus are needed for building system tests. These apparatus require regular maintenance and trained personnel for reliable operation. These apparatus include large-scale climate simulators, calibrated hot boxes, and roof and attic test facilities. Some of the apparatus were originally designed to measure steady-state performance and technical and procedural modifications must be made to assess the dynamic performance of newly proposed systems and materials.
H	Small Scale Facility Requirements	Small scale test apparatus are needed for material tests. These apparatus require regular maintenance and trained personnel for reliable operation. These apparatus include air flow permeability test apparatus, heat flow meter apparatus, small-scale climate controlled chambers, analytical balances, pressure plate apparatus, etc. Some of the apparatus were originally designed to measure steady-state performance and technical and procedural modifications must be made to assess the dynamic performance of newly proposed systems and materials.
I	Structural	There are conflicts between structural support

[63] *Technology Roadmap: Whole House and Building Process Redesign, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.

Barrier	Title	Description
	Support Requirements	requirements and the need to limit heat flow paths between the conditioned space and the external environment.[64]
J	Material Property Data	Data are unavailable for a number of critical material properties. Physical models are unable to accurately predict performance without accurate material property data.
K	Benchmark System Data	Benchmark performance data are unavailable for a number of existing systems and for all novel/proposed systems.

3.5.8 Envelope Strategies for Overcoming Barriers/Challenges

Durability issues, lack of technical data, and insufficient standards are key barriers that are preventing more energy efficient building envelopes from becoming routine practice. Moisture is responsible for the largest percentage of building envelope failures, leading to losses in energy efficiency, structural failures, and poor indoor environmental quality.

The major components of strategy for enabling technology research to address market barriers are:

- Apply world class scientific and engineering analysis to solve building envelope issues, e.g., moisture control, identified by Building America and others.[65, 66]
- Provide impartial expertise and/or leadership to standards organizations, such as ASTM, ASHRAE, CRRC, and IEA and government agencies.
- Leverage public resources with industry collaborations through User Centers with unique experimental facilities.[67]

[64] *Technology Roadmap: Advanced Panelized Construction, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.
[65] *Technology Roadmap: Whole House and Building Process Redesign, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.
[66] *Building America Meetings Series: Quarterly All-Teams Planning Meeting Notes*, November 16-18, 2004, U.S. Department of Energy, Building America Program. Washington, DC.
[67] *Technology Roadmap: Advanced Panelized Construction, 2003 Progress Report*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

Table 3-41 Envelope Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	First Cost Sensitivities	First, work to reduce the cost of advanced envelope technology. Second, improve communication with the general public to raise their awareness and increase their demand for better buildings. Third, promote the incorporation of improved technology into standards that must be used by the industry.
B	Resistance to Change	Work to incorporate the advanced technology into codes and standards that must be followed by industry. Continue with education programs to expand the knowledge base among building industry members.
C	Local Code Variability	Continue to work with standards organizations that local code officials rely upon. Expand communication with the general public to raise their awareness and increase their demand for better buildings. Make supporting information available to other elements of the DOE buildngs program that interact directly with code officials.
D	Thermal Performance versus Durability Performance	Continue cooperative product development programs and continue ambitious testing programs that include both age-acceleration and field-exposure elements in conjunction with laboratory thermal performance testing programs. Use work with standards organizations to accelerate adoption of new energy-conserving products and systems.
E	Unknown Interactions	Expand modeling capabilities, with important benchmarks extracted from both field tests and large laboratory experiments.
F	Material Developments	Work with building envelope component manufacturers to identify possible modifications that improve energy performance with minimal changes to application mechanics.
G	Large Scale Facility Requirements	Upgrade three aspects of the facilities (as budget becomes available). These three aspects are: (1) Replace worn-out components, increase capacity, increase

Barrier	Title	Strategy
		part-load capabilities (e.g., refrigeration compressor capabilities are often a limiting factor in test programs); (2) Develop and evaluate transient test procedures; (3) Upgrade control hardware and software in light of transient test procedure requirements.
H	Small Scale Facility Requirements	Upgrade three aspects of the facilities (as budget becomes available). These three aspects are: (1) Replace or repair worn-out components; (2) Develop and evaluate transient test procedures; (3) Upgrade control hardware and software in light of transient test procedure requirements.
I	Structural Support Requirements	Use modeling capabilities to explore the thermal performance of proposed new building configurations.
J	Material Property Data	Continue to make the sophisticated measurements necessary to expand the data library. Also, develop new measurement techniques as appropriate.
K	Benchmark System Data	Collaborate with industy, using unique experimental facilities to make needed experimental measurements.

3.5.9 Envelope Tasks

The Envelope subprogram will focus on the following tasks over the next five years.

Task	Title	Duration	Barriers
1	Moisture-related issues with weather resistive barriers	40 quarters	B. Resistance to Change, C. Local Code Variability, D. Thermal Performance versus Durability Performance, E. Unknown Interactions, J. Material Property Data, K. Benchmark System Data
2	Below-grade solutions to moisture problems	40 quarters	C. Local Code Variability, D. Thermal Performance versus Durability Performance, E. Unknown Interactions, K. Benchmark System Data
3	Hygrothermal model development	32 quarters	C. Local Code Variability, D. Thermal Performance versus Durability Performance, E. Unknown Interactions H. Small Scale Facility

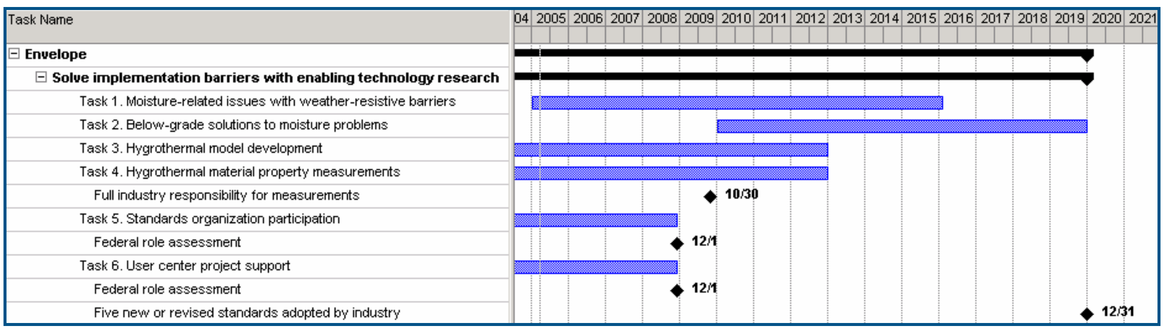
Task	Title	Duration	Barriers
			Requirements, J. Material Property Data, K. Benchmark System Data
4	Hygrothermal material property measurements	32 quarters	J. Material Property Data
5	Standards organization participation	32 quarters	A. First Cost Sensitivities, B. Resistance to Change, C. Local Code Variability E. Unknown Interactions
6	User center project support	32 quarters	A. First Cost Sensitivities, B. Resistance to Change , G. Large Scale Facility Requirements, K. Benchmark System Data
7	PCM enhanced fiber insulation	24 quarters	E. Unknown Interactions, F. Material Developments, G. Large Scale Facility Requirements
8	Fiber insulation with improved radiation properties	24 quarters	F. Material Developments, G. Large Scale Facility Requirements, H. Small Scale Facility Requirements, K. Benchmark System Data
9	Next generation colored reflective wall finishes	12 quarters	A. First Cost Sensitivities, D. Thermal Performance versus Durability Performance, F. Material Developments, K. Benchmark System Data
10	Membranes with varying hygrothermal properties	28 quarters	D. Thermal Performance versus Durability Performance, E. Unknown Interactions, F. Material Developments, G. Large Scale Facility Requirements, H. Small Scale Facility Requirements
11	Designer sheathing materials	24 Quarters	A. First Cost Sensitivities, C. Local Code Variability, D. Thermal Performance versus Durability Performance, F. Material Developments, G. Large Scale Facility Requirements, I. Structural Support Requirements, K. Benchmark System Data
12	Novel nanostructured membranes	20 quarters	D. Thermal Performance versus Durability Performance, F. Materials Development, J. Material Property Data, K. Benchmark System Data
13	Energy impact of alternative ventilation schemes	24 quarters	B. Resistance to Change, C. Local Code Variability, E. Unknown Interactions, G. Large Scale Facility Requirements, K. Benchmark System

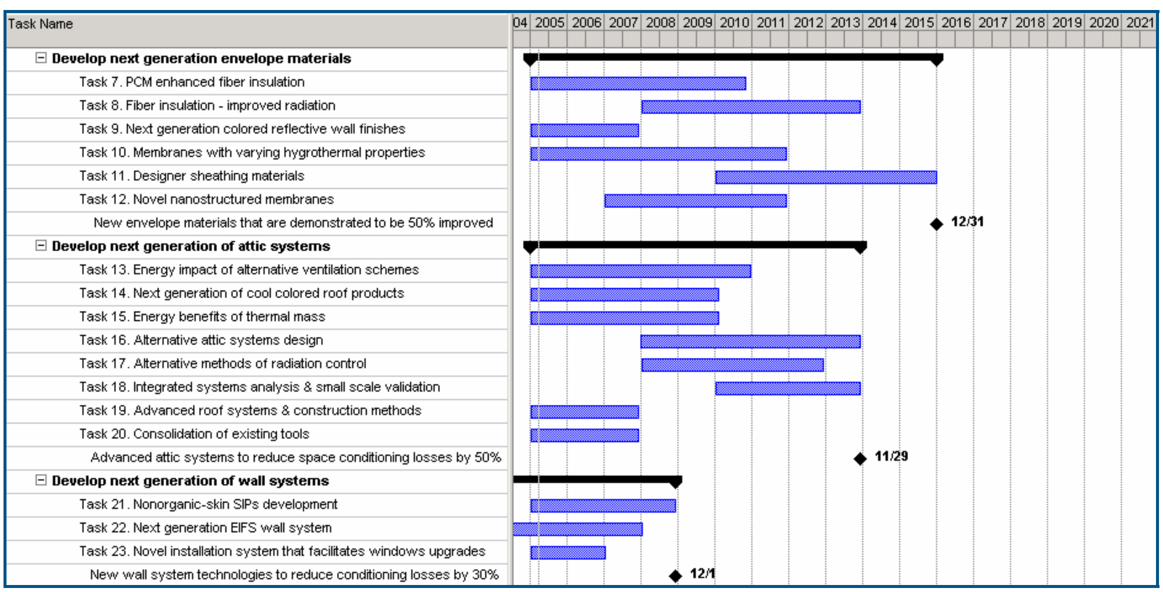
Task	Title	Duration	Barriers
			Data,
14	Next generation of cool colored roof products	20 quarters	A. First Cost Sensitivities, D. Thermal Performance versus Durability Performance, G. Large Scale Facility Requirements, K. Benchmark System Data
15	Energy benefits of thermal mass	20 quarters	E. Unknown Interactions, F. Material Developments, G. Large Scale Facility Requirements, H. Small Scale Facility Requirements, K. Benchmark System Data
16	Alternative attic system design	24 quarters	B. Resistance to Change, C. Local Code Variability, E. Unknown Interactions, G. Large Scale Facility Requirements, K. Benchmark System Data
17	Alternative methods of radiation control	20 quarters	D. Thermal Performance versus Durability Performance, E. Unknown Interactions, G. Large Scale Facility Requirements, K. Benchmark System Data
18	Integrated systems analysis & small scale validation	16 quarters	E. Unknown Interactions, G. Large Scale Facility Requirements, K. Benchmark System Data
19	Advanced roof systems & construction methods	12 quarters	D. Thermal Performance versus Durability Performance, E. Unknown Interactions, F. Material Developments, J. Material Property Data
20	Consolidation of existing tools	12 quarters	B. Resistance to Change, E. Unknown Interactions, K. Benchmark System Data
21	Nonorganic-skin SIPs development	20 quarters	A. First Cost Sensitivities, B. Resistance to Change, C. Local Code Variability, D. Thermal Performance versus Durability Performance, F. Material Developments, G. Large Scale Facility Requirements, I. Structural Support Requirements, K. Benchmark System Data
22	Next generation EIFS wall system	12 quarters	A. First Cost Sensitivities, B. Resistance to Change, C. Local Code Variability, D. Thermal Performance versus Durability Performance, F. Material Developments, G. Large

Task	Title	Duration	Barriers
			Scale Facility Requirements, I. Structural Support Requirements, K. Benchmark System Data
23	Novel installation system that facilitates windows upgrades	8 quarters	A. First Cost Sensitivities, B. Resistance to Change, C. Local Code Variability, D. Thermal Performance versus Durability Performance, G. Large Scale Facility, K. Benchmark System Data

3.5.10 Envelope Milestones & Decision Points

Figure 3-17 Envelope Gantt Chart





3.6 Windows

Table 3-42 Windows Summary

Start date	1980
Target market(s)	Subprogram focuses on new and existing residential buildings and new and existing commercial buildings.
Accomplishments to date/Past Activities	The BT Windows R&D program was instrumental in the development of Low e windows that offer significant heating and cooling load reductions. The case study was documented by the National Academy of Science and demonstrated a tremendous cost/benefit ratio for taxpayer's investment.[68] Instrumental in supporting development and widespread use of spectrally selective glazings to reduce cooling load impacts but allow daylight and view. Demonstrated technical feasibility of thin film Dynamic Windows; supported industry efforts to achieve market ready first generation products. Measured energy savings with first generation products. Developed innovative methods for plasma assisted sputtering to improve energy efficient windows (R&D 100 Award) Highly Insulating Windows- first field demonstration of window products that outperform insulated walls in cold climates. Enabling Technology Research for Efficient Products- suite of software tools in widespread use throughout the industry leading to rapid innovation and product development cycle, reducing the time it takes industry to develop a new product from months to weeks or even days. Partnered with industry in development of NFRC window energy rating system, now used to rate over 100,000 products in U.S. and referenced by ENERGY STAR Window program and most state and federal standards. Daylighting and Advanced Façade Systems- demonstrated measured lighting energy savings of 40-70% in daylighting applications; completed handbook and initial web site to provide design guidance.
Current activities	Dynamic Windows – first generation smart windows introduced to market; coating improvements aimed to reduce market prices; initial field test results define issues and potentials; technical progress in second generation alternative designs.

[68] *Energy Research at DOE: Was it Worth It? Energy Efficiency and Fossil Energy Research 1978 – 2000*, 2001, National Academies Press. Hereafter, NAP.

	Highly Insulating Windows – progress in aerogel development; new concepts for high R windows using gas fills and low-E coatings; thermally improved frames for commercial buildings under development. Enabling Technology Research for Efficient Products – development of WINDOW 6 and supporting THERM, Optics modules, adding complex glazings and shadings to the tool suite. Daylighting and Advanced Façade Systems – enhancement of the Commercial web site, development of COMFEN software tool prototype; field measurements of integrated daylight dimming and motorized shades leading to largest procurement of these systems in U.S.
Future directions	Dynamic Windows – reduced manufacturing costs and improved switching range and durability for first generation coatings; new second generation coatings that intrinsically provide better performance at lower costs. Extensive field testing to develop operations strategies that optimize energy performance and comfort. Highly Insulating Windows – improved aerogel and vacuum glazings at lower costs; multilayer glazing, low-E and gas filled windows reaching R10 glass values; improved sash and frame insulating values. Enabling Technology Research for Efficient Products – complete modeling capabilities for complex glazings and shadings within the WINDOW suite; examine other applications for software and other functionality that should be added to serve industry needs. Daylighting and Advanced Façade Systems – explore and develop new high performance optical materials for daylight control; continue façade integration studies, e.g. as with NY Times, with the goal of providing hardware and software to optimize energy performance and comfort. Complete a suite of tools for specifiers, consultants, architects, engineers and owners for engineering and optimizing high performance facades.
Projected end date(s)	2020
Expected technology commercialization dates	Dynamic Windows: 2007 – 2015 Highly Insulating Windows: 2007 – 2015 Enabling Technology Research for Efficient Products: 2007 – 2020 Daylighting and Advanced Façade Systems: 2008 – 2020

3.6.1 External Assessment and Windows Market Overview

Windows typically contribute about 30 percent of overall building heating and cooling loads[69] with an annual impact of about 4.7 quads, with an additional potential savings of 1 quad from daylight use. It will thus be virtually impossible to meet BT's ZEB goals without an aggressive program to change the energy-related role of windows in buildings. Windows are a unique building element in that they have the technical potential to supply useful energy services to a building by virtue of providing solar heat gain in winter and daylight year round, thus contributing to the BT ZEB goals. The overall BT approach is to first convert windows from their current role as significant thermal losses to the point where they are energy neutral (where useful gains just equal reduced losses), and then move to a higher level of performance where they contribute to a net energy surplus in a ZEB, thus offsetting other building energy uses.

The role of windows as a "net energy gainer" is a unique role for windows relative to most other building systems. Furthermore building owners do not need to be convinced to "add windows" to their buildings to save energy - they will always choose windows for view, aesthetics etc. But they do need to have the right high performance window technologies available to specify from the marketplace, and they need to know which window technologies, sizes and applications are best for which building type, orientation and climate. Windows are intrinsically multifunctional – the same product that must minimize solar gain in the summer should maximize it in the winter; the same product that provides useful daylight must minimize glare. This represents a significant challenge to manufacturers, specifiers and owners, because these dynamic functions are not well served by current technology.

The term "Windows" is used generically here for a wide range of "fenestration systems," combinations of glazing, sash, frames, shading elements and other energy control features. These can be inserted into vertical walls, or become the entire façade, they can be used in sloped glazing applications, and they are used as skylights and other forms of roof glazings. Custom units are applied to light wells, light pipes and other daylighting redirection technologies. Windows are applicable in all building types in all parts of the country. About 60 percent of window sales are to the residential sector and 40 percent to commercial, so that this program targets both types of buildings. Approximately half of all windows sold are in new construction and half are installed in existing buildings so that both new construction and renovation are included in the R&D program.[70]

The energy and demand impacts of windows are complex in that they do not intrinsically consume energy resources. A window can add to a heating or cooling load, thus requiring energy to maintain comfort. But a window can provide heat to a home in winter without being hooked to a gas line or electric line as a furnace must be. A window can also comfortably light a room throughout most of the day without requiring a hookup to the electric grid. Since windows are not directly connected to metered and purchased

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[69] BED

[70] *Characterization of the Non-Residential Fenestration Market*, Lawrence Berkeley National Laboratories and Northwest Energy Efficiency Alliance. Prepared by Eley Associates, November 2002. Report No. 02-106.

energy flows their impacts on building energy use are via other building systems, such as space conditioning and lighting. These linkages are sometimes complex and the net quad impacts of these systems in buildings must typically be calculated rather than metered.

The broad vision of the Windows R&D program is to convert windows from their current role as energy users to that of net energy suppliers, as part of DOE's ZEB vision. In order to provide net benefits the functions of windows must be significantly improved in terms of their impacts on heating, cooling and lighting. Furthermore, they must change their role from that of a static element to a dynamic element since the performance requirements change by hour, season and weather conditions. The details also vary with building type and location but the general "framework" of the strategy is clear. In winter, thermal losses must be greatly reduced and solar gain can be captured when available, subject to comfort requirements, e.g. no overheating. In summer, sunlight must be carefully controlled and typically excluded, subject to admitted view and daylight. Daylight is desired in almost all seasons and conditions, subject again to comfort constraints. The challenge that emerges is of a window system whose function and therefore properties must change dramatically throughout the year, thus leading us in the direction of "smart, dynamic" systems as a key priority.

3.6.2 Internal Assessment and Windows History

Dynamic Windows: Dynamic windows, or Smart windows, have been a major element in the DOE program over the last decade. Early in the program extensive surveys of alternate smart window technology suggested that electrochromic technology was the most promising of all the alternative materials systems for use in smart windows, and that active control provided by these coatings was the best match for performance needs in buildings. The program accordingly focused on those materials rather than thermochromic or photochromic, recognizing that there were still benefits from a durable, low cost thermochromic or photochromic device. The technical complexity of developing working electrochromic windows with acceptable cost and durability is proving challenging, and technical goals have accordingly been extended into the future.

For the first generation electrochromic windows development, only one U.S. manufacturer, SAGE Electrochromics, has electrochromic glazings for sale in the U.S. but only in very low volume and at very high cost. SAGE won a 100 R&D Award in 2004. While the sputtered devices have good dynamic performance and reasonable durability the costs are still very high because production processes are slow. DOE is investing in continued support with SAGE to enhance manufacturing technologies to produce lower cost products with equal or better properties. This work parallels private investments that SAGE is making to produce units of larger architectural size. Alternative coating designs and other deposition processes may offer lower production costs. DOE is supporting additional more fundamental thin film deposition studies to determine if this is a promising approach to increase production rates and reduce costs.

For the second generation electrochromic windows development, DOE is conducting a portfolio of research, specifically to explore promising new approaches with reflective device. DOE is funding:

- LBNL to develop a reflective EC device based on metal hydrides. The advantage of this device design is a smaller number of thinner coatings which can be deposited faster at lower cost. Reflective devices can switch to lower transmission levels and will not heat up to the same extent as the absorptive devices in first generation products. The metal hydride design uses hydrogen gas to switch which may be stored in the IG unit itself. The approach shows promise for a first proof of concept device. LBNL won a 100 R&D Award in 2004 for its reflective hydride device. The interim goal is to produce a working small prototype at which time follow-on options would be assessed. Rockwell International is also developing a reversible electrochromic mirror technology for windows.
- Rockwell to demonstrate a 30 cm^2 mirror that balances requirements for switching speed and light transmittance using this technology.

With regard to alternate materials, a simpler thermochromic or photochromic coating could provide energy benefits, particularly if it was much cheaper than an electrochromic and still maintained a useful switching range. DOE is therefore supporting:

- Pleotint LLC to develop a thermochromic material that may meet these performance requirements. Pleotint is being funded through the Innovation and Inventions program to develop thermochromic windows.
- Los Alamos National Laboratory, which is conducting R&D on ionic tint organic devices capable of having positive durability results.
- The National Renewable Laboratory, which has initiated a fundamental exploratory nano-super capacitor electrochromic device that has demonstrated ion transfer. These projects were initiated through a competitive Laboratory Call in 2003.

Market acceptance requires that products meet rigorous durability requirements. NREL has built on its expertise in testing PV materials to do similar accelerated exposure testing and degradation analysis for EC devices using indoor weatherometers. NREL has also participated in international activities to develop improved test protocols that are used with standard commercial test machines. This work has been very helpful to the companies doing materials development and it has served as a useful screen to reject device designs that are not yet ready for field testing or further development.

Highly Insulating Windows: Since heat loss is the single largest national energy impact of windows Highly Insulating Windows have been part of DOE's research program since the 1980s. In the 1980s, DOE funded research on manufacturing and production techniques for both aerogel and vacuum glazing technologies. Both these technologies have offered the potentials for high levels of performance; however their commercialization has always been hindered by a number of factors: efficient manufacturing procedures, quality control, durability, and degradations in total unit performance due to edge effects.

In the late 1980s, with the availability of design tools which predicted the performance of modified insulating glass units (IGUs) with three and four layers of low-e glass and gas filled gaps, a joint DOE/BPA sponsored R&D and demonstration program proved the effectiveness of these center of glass designs. Since then, industry has offered various window products with highly insulating glazings but their market share and effectiveness are limited. Market share is limited by higher prices; due to an increase in materials cost, the fact that such products are custom order products and do not benefit from economies of scale. Demand is limited by the lack of public awareness of such products, and no recognition of these products as being better than Energy Star. Technical issues such as weight and long terms gas durability hinder acceptance and industry commitment to production.

DOE is currently funding limited research on highly insulating windows. A NETL project with Aspen Aerogel to develop a more economical production process for aerogel is nearing completion. DOE is not currently funding any research specifically on vacuum glazings but there are several ventures internationally aimed at commercializing this technology. Thermal stresses, compromised thermal performance due to edge and spacer short circuits, and cost hinder its deployment. Vacuum glazings are being sold in Japan as a replacement for single glazing (their thin overall width makes this a niche market). Recognizing the practical difficulties of a radically new glazing approach DOE is funding a three year project (FY 04-06) project at LBNL aimed at investigating the potentials for not non-structural, non-sealed center glazing layers in high performance multi-layer low-e gas filled IGs. With the exception of a new FY 2005 NETL project with TRACO to develop more insulating frames for commercial building fenestration products, all the efforts to date have only focused on the glazing systems and not on frame and edge effects in high performance residential windows.

Enabling Technology Research for Efficient Products: Begun in the late 1980s, DOE's Enabling Technology Research Program focuses on two broad areas (1) understanding the thermal and optical performance of window components and window systems and (2) developing knowledge and guidance on which products minimize energy use in specific applications (i.e. by building type, by climate). In each of these areas, DOE supported efforts have included fundamental research (development of heat transfer and optical algorithms and standards), incorporation of research results into software tools, and information products (published books, web sites). Most of the fundamental work to provide good models for specular glazings and residential window frames has been successfully completed. This effort assisted in the adoption of the NFRC voluntary rating system, its maintenance and continued development by industry, and the emergence of the Energy Star program for windows. The availability of powerful, accurate tools to predict the performance of "virtual" window designs has made compliance with changing codes easier and has stimulated the development of many new energy efficient products by major window manufacturers. A development process that formerly took months (develop a design, build a prototype, send to a test lab, evaluate hotbox data, redesign the unit) and tens of thousands of dollars can now be done in hours or days.

Current efforts are focused in the commercial sector to help bring commercial window product performance characterization up to residential performance. Specifically, DOE is:

- Developing optical properties characterization tools for non-homogeneous optical properties (such as fritted and patterned glass, and shading systems);
- Providing technical support of NFRC's efforts to rate products intended for commercial buildings; and
- Developing the COMFEN (design analysis) software tool, a design guide and first-generation commercial buildings website, which are covered in more detail in the next section.

Daylighting and Advanced Façade Systems: Daylighting was one of the initial focuses of the DOE program in the early 1980s with DOE sponsoring the first two international daylighting conferences in Phoenix and Long Beach. Some of the early DOE work successfully demonstrated techniques to extend the perimeter zone impact of daylighting using light shelves and light pipes. Several of the basic modeling tools such as Superlight, Radiance and daylight modeling subroutines in DOE-2 were developed in this time frame. Most work was reduced or stopped in the late 1980s in part to focus available resources on the thermal modeling of residential products and because the high cost of good daylighting controls for electric light meant that the energy savings weren't always captured. The control of daylight glare and solar gain was recognized early as a key issue and extensive DOE-2 optimization studies were undertaken and published that definitively identified the key performance issues and interdependencies between the façade elements and the building HVAC and lighting systems. To pursue the theme of integration several cost shared projects were undertaken with utility co-support to demonstrate the viability of motorized blinds as a daylight and solar gain control strategy. Although the field test programs were successfully completed and demonstrated large energy and demand savings, industry was not willing to develop and market the resultant technologies. Commercial façade systems in the U.S. evolved slowly with an emphasis on absorbing and reflective glass for large high rise buildings with reduced daylighting potential, and building codes began to push the market from single to double glazed solutions.

Over the last few years there has been a modest revolution in commercial façade systems and an increase in interest in daylighting solutions, driven in part by architectural design trends originating in Europe to move to more highly glazed facades with more transparent glass for view and daylight. In the U.S. climates, this design approach could lead to very high cooling loads and discomfort, but the rapid market penetration of a DOE developed innovation, spectrally selective glass, has partially helped in this regard. DOE co-sponsored a report and workshop with utilities to explore the design trends for highly glazed buildings. DOE developed a book that provides design guidance and a first generation of a companion web site to provide more robust design data. DOE's next step in the process of supporting design optimization needs is to develop COMFEN, an easy to use computer-based tool that will help designers optimize glazing and façade systems. In the area of daylighting technology although little new technology development work is underway the smart glazing projects described earlier are all relevant solutions for daylighting control although they are not yet commercially viable.

3.6.3 Windows Approach

Development of cost effective, highly efficient glazing and fenestration systems for all building types and all parts of the country will require a portfolio of projects that address the key objectives outlined above. The general approach for the subprogram is therefore to conduct a tiered research and development program with several key elements:

1) R&D on smart glazings, insulating window systems, and daylighting technologies;
2) Lab and field testing to quantify and demonstrate the benefits of new technologies for industry; and
3) Development of improved analytical tools and software to enhance the ability of industry to assess, adopt and commercialize new technologies, thereby reducing industry risk.

Traditionally, the building industry has been slow to innovate, and once proven, innovation changes the marketplace slowly. The commercialization of low-E and other innovations has been studied to better understand the drivers that support successful innovation. Based on this work the program leverages several market realities to overcome obstacles in the marketplace:

1) The fenestration marketplace serves a variety of distribution pathways, price points and architectural styles. Early adopters (and therefore potential partners) may be large existing manufacturers (e.g. Andersen windows led the market with Low-E products) or a smaller niche player catering to a specialty market (Southwall offered highly insulating glazings in the 1990s).
2) The "ideal" window that works everywhere is a fiction. The variation in building type, climate, orientation, human factors, etc means that multiple solutions must be developed to meet national needs.
3) Windows serve numerous non-energy needs, e.g. view, acoustics, appearance, and are highly desired by most building owners. Coupling energy functions with other desired occupant benefits is a strategy for maximizing market impacts of efficient products. Low-E market penetration was accelerated by the marketing arguments for improved comfort and UV-fading resistance.
4) Windows will increasingly become dynamic and "smart" with sensors and active control elements. These units must be integrated with other smart building elements, e.g. dimmable lighting, and integrated into the overall building control system.

The program approach is based on the need to leverage resources with others whenever possible, consistent with technical objectives. The approach targets:

1) Breakthrough, high risk technologies that are likely to product large energy savings if successful;

2) Technologies that have the potential to be readily adopted by industry; and
3) Technology areas in which industry under invests, i.e. there is no profit motive to engaging in the R&D, e.g. simulation tools, or there are no established market mechanisms to support the effort e.g. daylighting projects involving lighting integration.

3.6.4 Windows Strategic Goals

Given the conceptual performance evaluation of windows in the nation's building stock the Windows R&D element has four objectives. They are listed below with a rationale for how the generic performance requirements above are translated into these objectives.

Objective 1: Dynamic Windows. Develop optical switching coatings that provide dynamic control of sunlight over a wide range (center glass: Visible Transmittance VT: 0.65 - 0.02; SHGC: 0.5 - 0.08) while meeting market requirements for cost, size, durability, appearance and which can be integrated into building control systems to provide energy, demand and comfort improvements in all buildings in all climates.[71]

Objective 2: Highly Insulating Windows. Reduce heat loss rates of windows and skylights from current market values (Energy Star) of 0.35 to 0.1 Btu/^{o}F-hr-ft^{2} using technology solutions that meet market needs for cost, optical clarity, weight, durability, manufacturability, etc. Provide solutions with high solar heat gain for use in northern climates. The overall objective includes not only improvements in center of glass but with edge and frame conditions also.[72]

Objective 3: Enabling Technology Research for Efficient Products. Develop the tools and resources needed to accurately predict component, product and systems thermal, optical and energy performance under a full range of operating conditions. Objectives need to be quantitative. [73]

Objective 4: Daylighting and Advanced Façade Systems. Develop daylighting technologies that displace 50-90% of annual electric lighting needs in perimeter zones,

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[71] The range of control is needed to provide the equivalent of a clear window in the clear state and a highly reflective window that can modulate bright sun to comfortable levels. The range of control can be provided functionally in two ways: intrinsically in the glass system, or as an "add-on" shade, blind or similar element that modifies the window properties. These "mechanical" devices inevitably have operating mechanisms that require replacement periodically. Thus the ultimate objective for the industry is to provide the control function within the glass system.

[72] An end use breakdown of window energy impacts shows that heating energy is currently the largest end use. The most direct way to reduce heating energy is to reduce thermal losses as addressed in this objective. The reduction in U value must be balanced by providing a suitably high solar heat gain coefficient in winter to capture sunlight.

[73] Windows are unlike almost any other building system in that a single set of windows will never provide optimal performance in all building types and climates. State of the art measurement and simulation tools are essential to guide public and private sector R&D investments in new technology, to guide architects and engineers in their integrated design of complete building systems, and provide feedback on how actual field performance compares to predictions. These tools and resources provide enormous leverage since they are made available to the entire industry, and have been shown to be accurate and unbiased. .

and extend perimeter zones to increase building-wide savings. Develop integrated façade solutions that achieve net 60-80% energy and demand savings compared to facades that meet ASHRAE requirements for typical climates.[74]

3.6.5 Windows Performance Goals

The table below lists the performance measurement targets for the Windows and Daylighting element. All performance measurements are relative to historical baselines that have been set as the baseline new construction in 2003.

[74] The single largest energy use in most commercial buildings is lighting and the use of daylighting technologies in smart facades to capture daylighting benefits addresses this need. To offset electric lighting energy three requirements must be met: daylight must be admitted and distributed as needed; overall intensity must be controlled to provide glare control and prevent overheating or adverse cooling impacts; and electric lighting must be controlled, e.g. dimmed, to save energy and reduce demand. Success thus requires a degree of integration that is not currently available in U.S. markets.

Table 3-43 Windows Performance Goals

Characteristics	Units	Calendar Year				
		2003 Status	2007 Target	2010 Target	2015 Target	2020 Target
Dynamic Solar Control	Price/Sq Ft.	$85-100	$50	$20	$8	$5
	Size (Sq. Ft.)	8	16	20-25	25+	25+
	Visual Transmittance	60 to 4%	60 to 4%	65 to 3%	65 to 2%	65 to 2%
	Solar Heat Gain Coefficient	0.50 to 0.10	0.50 to 0.10	0.53 to 0.09	0.53 to 0.09	0.53 to 0.09
	Durability* (ASTM Tests)	Med	High	High	High	High
Enabling Technology Research for Efficient Products	Tool Capability for Residential (R), Commercial (C) and New Tech. (N)	R- Yes C – No N- No	R- Fully C – Partial N – No	R- Fully C – Fully N - Partial	Assess need for industry support	Assess need for industry support
Highly Insulated Windows	U-Value	0.33-0.50	0.20-0.25	0.17	0.10	0.10
	Incremental Cost $/ft^2	IG Base cost: $3	5	5	4	3
Daylight Redirecting	Percent Lighting Energy Savings	40	50	50	60	60
	Perimeter Zone depth, Feet	12	15	20	20	30
	Incremental Cost $/ft^2	3	8	8	6	6

*Represents component durability, system reliability will be address in future years < 20K cycles – Low; 20K – 50K Cycles – Medium; > 50K Cycles – High

3.6.6 Windows Market Challenges and Barriers

Window designs and material selections are typically constrained by cost, performance and non-energy performance, including appearance. These parameters take on different weights in new vs. retrofit decision making and between residential and non-residential, and between owner occupied vs. leased space. Windows are a very "visible" element in most homes, unlike insulation which is hidden from view. But window performance is complex to understand and since windows do not directly consume energy their impacts on home or business energy bills is often misunderstood.

Table 3-44 Windows Market Challenges and Barriers

Barrier	Title	Description	Target
A	Lack of Educated Demand	There is a lack of "educated demand" for innovative products – builders and end users can be unaware of the significant benefits that are afforded by energy efficient window products.	Enabling Technology Research

3.6.7 *Windows Technical (Non-Market) Challenges/Barriers*

The fundamental technical challenge is to produce technologies that are so efficient that they can convert the window from a net energy loser to energy neutral, and then to a net energy gainer. In order for this to happen, we need windows with better fixed properties, e.g. much lower U-value, but we also need dynamic performance properties to tradeoff winter vs. summer, glare vs. view, daylight vs. solar gains that increase cooling loads. Finally, we need to capture the benefits of daylighting in all buildings and all climates, primarily in commercial buildings where the lighting bills are higher, but in homes as well. Each of the technologies defined here and in the table below must be integrated with other window elements and building systems. And finally the technologies and systems are not inherently self optimizing and self assembling; architects, engineers, homebuilders and homeowners need data and tools to guide decision making and optimization. Since windows are intended to last 20- 50 years[75] it is critical that good information be brought to bear on that decision since it can only be changed at great cost later.

The barriers to commercially available innovative window technologies were identified in the Windows Technology Roadmap, published in 1999. They are:

Table 3-45 Windows Technical Challenges/Barriers

Barrier	Title	Description
B	Technical risks inhibit investments	There are technical risks associated with industry's investment in new technology.
C	Inability to predict performance	Industry may be unable to adequately predict the performance benefits from new technology.
D	High first cost for innovative products	New technologies that can increase the energy efficiency of windows can lead to higher first cost for innovative window products.
E	Inadequate or inconsistent building codes	Building codes are dissimilar from state-to-state and across regions. They can also be poorly enforced, and inconsistent with national and international guidelines and codes.
F	Lack of integration tools	Industry lacks integration tools that are necessary to achieve system integration.
G	Durability issues	Industry lacks assurance that durability issues have been adequately addressed for advanced technologies.

Each of these represents areas where federal support can provide support to change the energy marketplace. The support can take different forms. In the case of high risk technical R&D, government support in the form of cost shared R&D reduces the risk for

[75] Historically windows have lasted over 100 years because they were single pane, since double pane windows have greater failure modes, the window industry is experiencing a paradigm shift.

companies to develop innovative technology. In other cases, R&D has been successfully concluded but the functional impacts of the technology are not well understood or believed by potential purchasers. In this case, field testing or other third-party testing provides accurate unbiased data on technology performance. Measurement and evaluation protocols are often not available for new technologies and DOE support can provide accurate unbiased approaches. In a similar way, specifiers and designers must have the analysis tools to assess performance of design options when new materials and systems are being used. The companies making the products often do not have the capability or resources to produce the tools and even if they did specifiers would be unwilling to trust them due to inherent conflicts in their role as provider of the product.

The ideal DOE role varies in different project areas. In terms of technology development there is a profit motivation for a company to complete the R&D and get the technology to market so that it can begin to earn money. Once the project moves beyond specific milestones the activity is completed from DOE's perspective. In other non- technology areas such as providing accurate information and tools, DOE may need to play a longer term role. In such a case the strategy may be eventually to develop a mechanism for those in industry who benefit from the service to pay for it, as has been done this past year with the International Glazing Data Base. Finally, DOE is not the only public sector partner with an interest in more efficient energy use and demand control. State energy agencies, non-profits, utilities, and other all have an interest in co-supporting public goods activities such as those supported by DOE. An explicit strategy in this program is to partner whenever possible with other parties for co-support of R&D. The electrochromic field test program is a good example where CEC has matched DOE's funding for a three year field test program.

3.6.8 Windows Strategies for Overcoming Barriers/Challenges

Table 3-46 Windows Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Lack of educated demand	Develop tools to inform consumers, recruit partners to maintain tools in the future.
B	Technical risks inhibit investments	In association with fundamental technology development, conduct case studies and field studies with partners.
C	Inability to predict performance	In association with the National Fenestration Rating Council, work to ensure all products (dynamic and highly insulating) are properly rated.
D	High first cost for innovative products	Fundamental research on dynamic and highly insulating windows is directly related to cost reduction.
E	Inadequate or inconsistent building codes	Provide fundamental tools regarding energy performance of windows so that other government and non-government organizations can promote code establishment.
F	Lack of integration tools	Develop control and system performance

Barrier	Title	Strategy
		algorithms to optimize dynamic and advanced façade systems for energy savings and peak demand reduction, while addressing comfort, glare and occupant acceptance.
G	Durability issues	Assist industry with the establishment of universal certification for today's and the next generation of fenestration products. Develop fundamental test protocols to predict durability.

3.6.9 Windows Tasks

Below are key task areas of research conducted in the Windows subprogram.

Dynamic Windows

- **Conduct research on advanced materials solutions.** Explore new switchable coating technologies that by their intrinsic design and/or materials selection have the potential of meeting all performance objectives. BT will conduct research on novel coating materials and new device designs, as well as breakthroughs in deposition process that can result in reductions in EC coating costs, allowing much greater market penetration.
- **Optimize first-generation coatings.** BT will work with industry to develop durability test procedures, optical measurement protocols, and NFRC rating procedures in support of advancing new technologies toward the marketplace.
- **Optimize systems integration solutions.** BT will develop control strategies that optimize the performance and value of smart glazings in terms of control of energy, demand and comfort. BT will also validate new sensors and control algorithms for optimizing EC system performance in conjunction with dimmable lighting and HVAC systems, and will verify and validate energy and demand savings, cooling and daylighting tradeoffs, and assess occupant benefits in terms of comfort and performance using a variety of base case glazing and shading conditions as well as solutions using electrochromic windows.

Highly Insulating Windows

- **Develop advanced materials solutions.** BT will develop advanced materials with innovative thermal properties can be used to reduce glazing heat loss in all building types. Technical progress must be matched with other research activity that integrates the new glazings into full frame and façade systems.
- **Develop low-cost, high-R value insulating glazing units.** The best performing windows in the U.S. market today have U-values in the range of 0.15-0.35. Many of these windows achieve these performance levels using multiple glass panes and gas filled air spaces. These designs tend to be heavy and costly and have not achieved significant market share. The cost and market acceptance of these prototypes are critical design features for consideration. The optimal tradeoffs for heat loss and solar heat gain must be considered for each climate.

Enabling Technology Research for Efficient Products

- **Develop tools to assist manufacturers in designing more efficient products.** In the past product innovation was slowed by the time and costs required to design and build a prototype, to test the prototype and assess its performance problems, to return to the shop to re-engineer the prototype and then to begin the process over until desired results are obtained. Powerful new computer tools have been developed that enable manufacturers to quickly and cheaply design and prototype new "virtual products." The same tool kit can be used to determine rating and labeling properties. Tools include software packages for heat transfer and solar gain through glazing, heat transfer through framing, and the associated data bases that are required to operate the tools. The tools need to be validated by DOE with state of the art measurement in appropriate thermal test facilities.
- **Provide technical assistance for DOE mandatory and voluntary programs.** DOE leverages its work by partnering formally and informally with other organizations that promote energy efficiency such as utilities and state and local agencies. DOE partners with these groups to ensure that its information is made available to those activities to encourage widespread adoption of the energy efficient windows. One of the largest beneficiaries of the DOE Windows R&D activity is the Energy Star windows program which is based in part on simulation results from DOE tools.

Daylighting and Advanced Façade Systems

- **Develop daylighting technologies.** Develop and assess performance of new daylighting technologies that increase savings in perimeter spaces and permit deeper penetration of daylight allowing extension of the effective zone of daylighting savings. Compared to 20 or even 50 years ago there are few products today on the market that employ significantly different optical performance to obtain better daylight management. (This contrasts with thermal management where there have been major advances.) Optical technologies continue to evolve quickly in other fields and some represent a potential use in buildings. Scan emerging optical technologies, assess the subset that make sense for use in buildings, and develop these into viable products. Several high performance systems are in the marketplace for roof lighting applications, e.g. light pipes, so the near term emphasis is on optical systems for vertical facades.
- **Façade system integration and optimization.** Façade systems use more than glazing and framing. The best systems today employ some form of dynamic shading and link to dimmable lighting controls. Develop control algorithms, new sensor technology, shading controllers, etc. and demonstrate overall performance of the complete system in test facilities and the field. Undertake collaborative work with IEA and other international partners as a vehicle for exploring more options at lower cost and gaining access to additional product and performance data.
- **Field testing of façade systems.** Façade systems are complex entities whose overall operation is often more that the sum of the parts. Many aspects of

performance can best be assessed by direct observation and extensive testing in a completed building. Other systems and accurate data for calibrating simulation models can best be obtained in highly instrumented controllable facilities where comparative and absolute measurements can be made under controlled conditions. DOE funded the construction of a unique three room test facility which has been designed to accommodate a range of window and façade systems. To date the facility has been used extensively for electrochromics testing but it could be adapted to serve other facade testing needs.

- **Develop information resources for system designs.** Develop a series of decision support materials to assist designers and building owners to select appropriate daylighting and façade systems. This includes a tiered set of tools to address the differing needs of different users, e.g. a book, a website and a variety of other information resources including a custom annual energy model specifically for fenestration performance assessment at the whole building level, as well as addressing non-energy impacts, e.g. glare, that are critical to decision making.

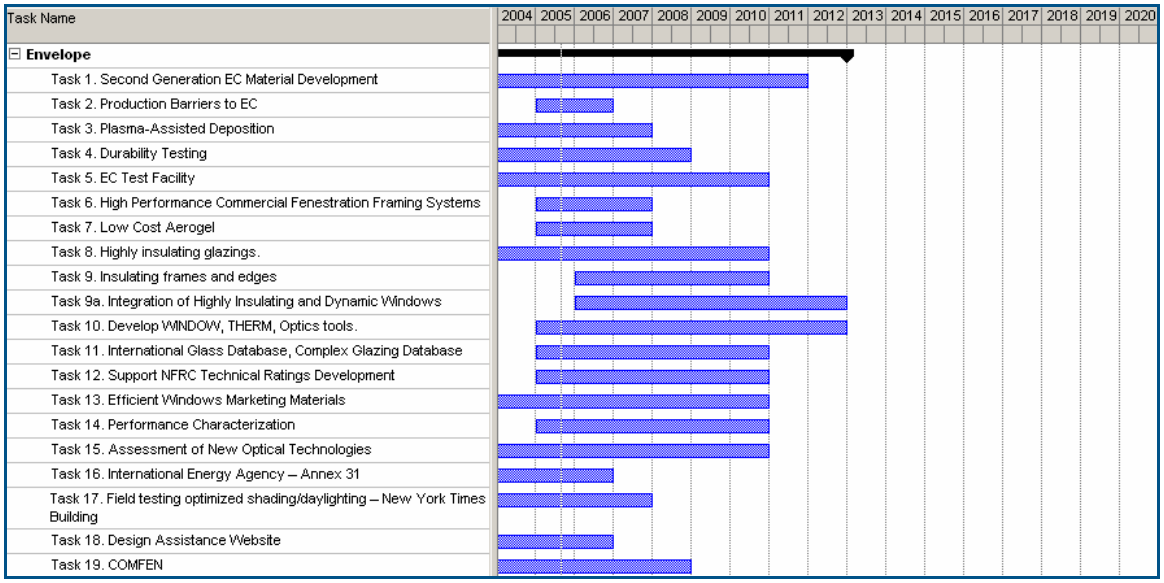
Table 3-47 concisely overviews DOE's currently planned or funded core tasks related to the above areas.

Table 3-47 Windows Tasks

Task	Title	Duration
1	Second Generation EC Material Development	2004-2011
2	Production Barriers to EC	2005-2006
3	Plasma-Assisted Deposition	2004-2007
4	Durability Testing	2000-2008
5	EC Test Facility	2003-2010
6	High Performance Commercial Fenestration Framing Systems	2005-2007
7	Low Cost Aerogel	2005-2007
8	Highly insulating glazings.	2004-2010
9	Insulating frames and edges	2006-2010
9a	Integration of Highly Insulating and Dynamic Windows	2006-2012
10	Develop WINDOW, THERM, Optics tools.	2005-2010
11	International Glass Database, Complex Glazing Database	2005-2010
12	Support NFRC Technical Ratings Development	2005-2010
13	Efficient Windows Marketing Materials	2001-2010
14	Performance Characterization	2005-2010
15	Assessment of New Optical Technologies	2004-2010
16	International Energy Agency – Annex 31	2002-2006
17	Field testing optimized shading/daylighting – New York Times Building	2004-2007
18	Design Assistance Website	2004-2006
19	COMFEN	2004-2008

3.6.10 Windows Milestones & Decision Points

Figure 3-18 Windows Gantt Chart



3.7 Analysis Tools

Table 3-48 Analysis Tools Summary

Start date	1977
Target market(s)	Architects, engineers, energy consultants, researchers, standards developers, building owners
Accomplishments to date/Past Activities	Developed a series of increasingly more sophisticated energy analysis tools, collectively named DOE-2. This was ended in 1997. Since 1995, developed 8 releases of a new-generation energy simulation program, EnergyPlus.
Current activities	Development, validation and testing of increasingly more capable energy simulation program, EnergyPlus.
Future directions	Development of EnergyPlus capabilities to support BT research and deployment activities for net-zero energy buildings.
Projected end date(s)	2020
Expected technology commercialization dates	Commercialization of EnergyPlus began in 2001 with release of first version (1.0). Continuing with other releases.

3.7.1 External Assessment and Analysis Tools Market Overview

Architects, engineers, and other building designers have always "envisioned" buildings before construction begins. In the 20th century this process began with pencil sketches and inked drawings. These 2-D representations were sometimes supplemented with 3-D scale models to better understand spatial relationships and appearance. The engineering side of construction was supported by an elaborate infrastructure of tables and manuals that documented workable solutions derived from analytical calculations, cumulative empirical data and the rules of thumb widely used in the construction industry. With built-in safety factors and incremental advances based on new findings these approaches were adequate to support the slowly evolving buildings sector through most of the last century.

With the price shocks of the 1970s, interest in building energy efficiency changed the information management needs of designers. The subsequent availability of cheap desktop computing and its software infrastructure continue to revolutionize virtually all aspects of design and construction. However, in most cases computers are relegated to doing conventional tasks, albeit more quickly and accurately. But there are also emerging opportunities where computers and simulation tools can provide novel analysis of complex interactions between systems and new performance insights that are revolutionizing building design and operation. Computers are certainly useful tools to sum up the overall heat loss of a building more accurately and quickly than by hand. But powerful new simulation tool – which in a few minutes can calculate the behavior of building control systems and the resultant impact on energy use, peak demand, equipment sizing and occupant comfort – provide performance insights that have been previously unattainable. It is precisely these insights that are needed if the building community is to break away from a "business as usual" approach to energy use in buildings.

The Energy Bill tax credit legislation could create both opportunities and challenges for the Analysis Tools program. Depending on how the credit is implemented, DOE may have to develop processes for verifying whether a particular building has achieved enough energy efficiency to qualify for the tax credit including certification of energy analysis tools.

Also, the California Energy Commission is evaluating whether to move from DOE-2.1E for development and compliance with their 2008 Title 24 Standards (mandatory California building energy standards). Decision is expected late in 2005.

With software tool development dating back to the 1970s, BT software tools are the benchmark against which other tools are tested. The predecessor program to EnergyPlus, DOE-2.1E, currently is the underlying calculation engine[76] for more than 20 tools and the basis for building energy standards development and research throughout the world. The National Academy of Sciences in their review of the value of energy research at DOE, found:

[76] DOE BT develops an unbiased, reliably tested 'engine' for calculating building energy flows. This engine is then used by the private and public sectors in the underlying calculation engine for a wide variety of tools and user interfaces.

> The development of this computer program [DOE-2.1E] also stimulated the promulgation of performance-based standards that provided designers with multiple ways to meet particular efficiency targets. The committee concludes that DOE-2 was influential in the development of both California's Title 24 and the American Society of Heating, Refrigerating and Air-Conditioning Engineers standards that have guided the development of building standards throughout the United States (and indeed the world). Compliance with these standards has resulted in significant energy, environmental, and security benefits.[77]

To achieve balance in the [research] portfolio, a broad range of considerations should be addressed, including the following:

> Provision of enabling tools to help facilitate market penetration of new energy efficiency technologies (as, for example, in the case of the development of the DOE-2 family of computer design and analysis tools); …[78]

> The most significant uses of DOE-2 have probably been for support of demand-side management and rebate programs by utility companies, support for the development and implementation of voluntary and mandatory energy efficiency standards, and as a tool for teaching and research in architectural and engineering schools.[79]

> …the use of DOE-2 confirmed to decision makers that substantial energy could be saved by incorporating and assuring the performance of certain sets of building systems, subsystems, and components into the building design, retrofit, or operations.[80]

> ...simulation models (i.e., software tools or instruments, such as DOE-2) are critically important enablers of decisions to improve energy economics, environmental quality, and security.[81]

> ...enabling tools such as DOE-2 do not themselves save energy. Rather, they provide methods by which energy-saving alternatives can be evaluated.[81]

BT-developed software tools have also been recognized by a broad range of awards including:

[77] NAP
[78] NAP
[79] NAP
[80] NAP
[81] NAP

Energy Plus has been recognized for several awards.

- EnergyPlus, R&D 100 Award, 2003
- EnergyPlus, Award for Excellence in Technology Transfer, 2002, Federal Laboratory Consortium
- EnergyPlus, Award for Excellence in Technology Transfer, 2004, Technology Transfer and Intellectual Property Office, Lawrence National Laboratory
- EnergyPlus, IT Quality Award for Technical Excellence, 2002, U S Department of Energy Chief Information Officer Annual Awards
- DOE-2, Energy 100 Award[82]

3.7.2 Internal Assessment and Analysis Tools History

For more than twenty years, the U.S. government supported development of two building energy simulation programs, DOE-2 and BLAST, with comparable capabilities. BLAST[83], sponsored by the U.S. Department of Defense (DOD), has its origins in the NBSLD program developed at the U.S. National Bureau of Standards (now NIST) in the early 1970s. DOE-2[84], sponsored by DOE, has its origins in the post office program written in the late 1960s for the U.S. Post Office. Both programs are widely used throughout the world. The main difference between the programs is in their load calculation method; DOE-2 uses a room weighting factor approach while BLAST uses a zone heat balance approach. Each program comprises hundreds of subroutines.

In 1994, DOE and DOD began discussing merging DOE-2 and BLAST programs and development efforts. Based on these discussions and the consensus reports from two workshops of users and developers in 1995, DOE initiated the development of the new program named EnergyPlus in 1996. The initial version of Energy Plus (V 1.0) was released in 2001. This version had about 50% of the capabilities found in the combined feature set of DOE-2 and BLAST while also addressing about 50% of the California Title 24 building performance standards capabilities (the bellwether for building energy standards in the US).

Current efforts (2005) focus on completing the incorporation of the most popular features and capabilities of BLAST and DOE-2. Additionally, the program is pursuing interoperability (data exchange) with popular building design software, extending the compatibility with Title 24 and other national and state building energy performance

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[82] *Department of Energy Honors Most Notable Scientific and Technological Accomplishments*, U.S. Department of Energy, Office of Science, January 8, 2001.

[83] Building Systems Laboratory. 1999. *BLAST 3.0 Users Manual*. Urbana-Champaign, Illinois: Building Systems Laboratory, Department of Mechanical and Industrial Engineering, University of Illinois.

[84] Winkelmann F. C., B. E. Birdsall, W. F. Buhl, K. L. Ellington, A. E. Erdem, J. J. Hirsch, S. Gates. 1993. *DOE–2 Supplement, Version 2.1E*, LBL-34947, Lawrence Berkeley National Laboratory. Springfield: National Technical Information Service.

standards, and exploring strategies for broader usage in the design community with interfaces to other, simpler simulation tools and through training and other activities. In the longer term, it is envisioned that EnergyPlus will become the premier tool for simulation of building energy use enabling high performance design and operation of commercial and residential buildings as well as a decision tool that can aid BT in determining a path towards ultra-low and even net-zero energy buildings.

BT has a considerable history and experience in creating computer software tools that emphasize the energy conserving aspects of building design. Since the mid-1970s, BT has sponsored (along with others) and supported many tools that help designers create better buildings. While this may seem an odd venture for DOE to be involved in and sponsoring, there are several good reasons for keeping this kind of activity in the public sector:

- Development of building energy simulation software is a high-risk venture for profit making companies. By assuming the risk of developing a simulation engine, BT opens the market to others; if public sector can assume the risk, then others can provide vehicles (such as domain specific interfaces) for designers to use.
- By focusing BT development on the “engine” of fundamental algorithms, this ensures accuracy in the tool as well as availability to the users at large, but can be given at no charge to users (in end-user form).
- Public sector funding allows the latest technologies to be incorporated in the tools – some before the technologies actually reach the marketplace. This can help condition the market and promote early adoption of state of the shelf building energy technologies.
- Public sector can emphasize validation and verification studies of both tools and technology – assuring accuracy to the users.
- Public sector can oversee and facilitate developments from a broad range of participants – university, industry research groups, other publicly funded research ventures.
- Tools form a quick basis for technology transfer of BT research. In addition, as a public sector initiative these tools will also promote energy conserving developments throughout the world.

In support of the long-term goal of ZEB, Analysis Tools are a key enabling technology for BT research, particularly in Commercial Integration and Residential Integration. These integration activities require methods for determining the most appropriate technology pathways.

The Analysis Tools subprogram complements and supports much of the work within BT-Commercial Integration, Residential Integration, Appliance and Equipment Standards, HVAC, Windows, and Building Envelope, in particular. It provides the underlying calculation engines (DOE-2 or EnergyPlus) for evaluating the impacts of proposed research and used in development of building standards. DOE-2.1E is used in the BEOpt-R optimization method used in Residential Integration. EnergyPlus is used directly in the

BEOpt-C optimization methods used in Commercial Integration. The Analysis Tools program also complements the Solar program by providing a means of testing Solar technologies integrated in a building. Similarly, FEMP research and deployment activities are supported by providing a means of calculating building energy savings.

3.7.3 Analysis Tools Approach

By 2015, BT research will develop, test, and release analysis tools which robustly support BT whole-building, component, and systems R&D; and support evaluation and decision-making of ZEB energy-efficiency and supply technologies and systems during new building design and existing building retrofit. A staged approach will be taken so that earlier releases will address a subset of the BT subprograms. In this staged approach, control and optimization will be addressed first (2007), followed by predictive controls (2008), and finally extension to emerging technologies (2009).

For all but the simplest buildings, architects and engineers require tools that permit rapid analysis of multiple design choices to assess costs and performance. Facility managers need greatly improved controls and energy information tools if they are to operate buildings efficiently under a wide range of normal conditions of occupancy, weather, and energy cost, as well as under dynamic conditions (e.g., real-time pricing and demand limiting), and finally under more stressful conditions, such as unusually high energy prices or extremes of weather conditions that last for hours, days, weeks or months. Product developers, researchers, educators and others need a tool with capabilities that go well beyond the limitations of today's widely used tools.

BT analysis tools must be organized around a shared, open building data model that allows each tool to transfer information seamlessly to others. On today's design projects, most designers routinely use CAD and cost-estimating tools. But they often don't use energy simulation tools, in part because of the time and cost of data input and output, all constrained by limited design fees. An open building data model (interoperability) makes it possible for energy simulators to quickly begin energy analysis using building design and geometry data imported directly from CAD tools.

The plan relies on three strategies to maximize the future potential energy savings:

- *Extend the capabilities of energy analysis tools*: Develop increasingly more robust versions of EnergyPlus that can be used to design net-zero energy and high performance buildings including advanced and near-market technologies and systems, building integrated PV, on-site CHP, controls optimization, and multizone airflow and pollution transport.
- *Validate Energy Analysis Tools*: Validate and test EnergyPlus calculations and performance. Extend IEA and ANSI/ASHRAE Standard 140-2004 to cover full matrix of validation methods for building simulation tools.
- *Deploy Analysis Tools*: Work with leading-edge A&E firms and key HVAC manufacturers to encourage their use of EnergyPlus software. The larger buildings tend to have some of the larger and more innovative designers. BT's Analysis Tools activities will focus on these high-value building projects that between them influence almost half of building energy use. Work with the

International Alliance for Interoperability to ensure that building energy is integral to the interoperability standards. Work with firms providing user interfaces by providing technical assistance with operational issues of EnergyPlus.

EnergyPlus and its related tools, databases and documentation are an accessible portal, filter and archive for critical knowledge generated from BT research. The tools activities within BT must be intimately linked to and supported by the other R&D and standards development activities to realize these benefits. As BT-developed technologies become market ready, BT tools will be ready with new modules which can easily allow others to simulate the benefits in an integrated, whole-building design or retrofit. From the perspective of the building industry, a suite of tools which continuously embodies the best of BT R&D will effectively attract and maintain private sector interest in and involvement with EERE programs, making the tools a powerful deployment vehicle for BT.

This will require a decision and commitment by BT management to adopt EnergyPlus through the BT subprograms. This would be a multiyear transition in each of the subprograms not yet using EnergyPlus. It would require a plan which identifies required capabilities that must be added to EnergyPlus and changes to the analytical infrastructure for each subprogram.

3.7.4 Strategic Goals

BT has established aggressive goals to create a new generation of residential and commercial buildings by 2025 that will have net-zero impact on non-renewable energy resources. Similar technologies and design approaches will also be applied to improve the performance of existing buildings. These ZEB goals cannot be met alone through research to significantly improve the performance of components (e.g., windows, appliances, heating and cooling equipment, lighting). It also requires a revolutionary approach to building design and operation that can achieve 70-80% reductions in load coupled with careful integration with onsite renewable energy supplies as well as thermal and electrical storage.[85] This in turn requires new capabilities in a powerful simulation tool that supports evaluation of new ZEB demand-reduction and energy-supply technologies, and that supports various decision points throughout the life cycle of building design and operation.

[85] Building energy performance, particularly in ZEB, is the result of interactions among many elements including climate (outdoor temperature, humidity, solar radiation and illumination), envelope heat and moisture transfer, internal heat gains, lighting power, HVAC equipment, controls, thermal and visual comfort, and energy cost—and these complex interactions cannot be understood and quantified without simulation tools. For example the effect of daylighting dimming controls on the electric lights with daylighting has several effects: lighting electricity use goes down as does the heat gain from lights. Lower heat from lights reduces cooling use (amount depends on cooling equipment efficiency), but in the winter it can significantly increase the heating energy. Thus the annual impact of daylighting on energy use requires detailed calculations that consider these interactions. In a series of field evaluation case study reports, NREL found that simulation tools were one of the essential elements for tuning the building design as well as the operating building performance.

The Analysis Tools subprogram is working with other BT subprograms to transition their simulation program needs to EnergyPlus. To support BT activities, EnergyPlus will have to be extended and the other BT subprograms will have to be trained and assisted in their transition. The focus continues on develop increasingly more robust versions of EnergyPlus that can be used to design net-zero energy and high performance buildings.

3.7.5 Analysis Tools Strategic Goals

The primary technical goal of this program is to establish BT software tools as the primary calculation engine for evaluating the design and operating energy performance of integrated low and net-zero energy buildings including control sensors, strategies, and systems; building performance in operation; and integrated airflow analysis.

3.7.6 Analysis Tools Performance Goals

The performance goals for this subprogram are shown in Table 3-49 and key goals include:

- Coverage of state-of-the-art building energy-efficiency and renewable energy and other ZEB technologies that analysis tools can evaluate
- Methods of Test Coverage of Whole-Building Analysis Tools
- BT subprograms that currently employ building simulation tools that use EnergyPlus for program research and analysis

Table 3-49 Analysis Tools Performance Goals

Characteristics	Units	Calendar Year		
		2004 Status	2008 Target	2010 Target
Extend the Capabilities:				
1. Coverage of state-of-the-art building energy-efficiency and renewable energy and other ZEB technologies that analysis tools can evaluate[86]	Percent	30	75	90
Validate Energy Analysis Tools:				
2. Methods of Test Coverage of Whole-Building Analysis Tools[87]	Methods Covered	2	4	6
Deploy Analysis Tools:				
3. BT subprograms that currently employ building simulation tools that use EnergyPlus for program research and analysis	Number of subprograms	2	6	11
4. Interoperability with other building design tools[88]	Percent	25	35	50
5. Design firms trained and provided continuing assistance on the use of EnergyPlus	Number	3	9	9
6. Extend EnergyPlus to other broader based engineering design tools (TRACE and HAP)	Number	0	2	2

[86] Including advanced and near-market technologies and systems, building integrated PV, on-site CHP/DER, controls strategies, predictive/optimization control systems, and multizone airflow and pollution transport.
[87] See Table 1.1.2 for current status of validation methods of test
[88] Includes CAD geometry, CAD HVAC, CAD lighting and electrical, HVAC design, cost estimating, and project management. Current status is full interoperability with CAD geometry (the most difficult issue for interoperability) and the capability for interoperability with CAD HVAC but there is no other tool yet able to share data.

Table 3-50 Status of Validation Method of Test Coverage: Analysis Tools

Method of Test Type[89]		Building Envelope	HVAC System and Plant
Analytical	Whole-Building Simulation	- Working Document of IEA Task 22 (Finland) - ASHRAE 1052-RP (OSU)	- ANSI/ASHRAE Standard 140-2004 [based on IEA HVAC BESTEST Vol. 1 (NREL)] - ASHRAE RP 865 (PSU/TAMU)
	Simplified Programs		- HVAC BESTEST Fuel-Fired Furnace (NRCan)
Empirical	Whole-Building Simulation	- ETNA/GENEC Tests (EDF) - BRE/DMU Tests (BRE)	-Iowa ERS tests for VAV, Daylighting-HVAC, and Economizer Control (Iowa ERS)
	Simplified Programs		
Comparative	Whole-Building Simulation	- ANSI/ASHRAE Standard 140-2001 [based on IEA Envelope BESTEST (NREL)	- ANSI/ASHRAE Standard 140-2004 [based on HVAC BESTEST Vol. 2 (NREL)] - RADTEST Radiant Heating (Switzerland)
	Simplified Programs	- HERS BESTEST (NREL) - Florida BESTEST (NREL)	

The strategic goal for Analysis Tools is to establish our software tools as the primary calculation engine of choice for evaluating the design and operating energy performance of integrated low and net-zero energy buildings. This objective will be measured by the percent coverage of state-of-the-art building energy-efficiency, renewable energy and energy supply technologies that EnergyPlus can evaluate as compared to other similar software including DOE-2 and BLAST. In this case, the objective is considered met when EnergyPlus can evaluate 90% (by 2010) of the state-of-the-art technologies under development (by 2010) or planned (by 2015) by BT R&D.

The second part of this first goal is to establish EnergyPlus as the primary software tool for BT program research, planning and analysis. This objective is measured firstly by the ability of EnergyPlus to address technical aspects of the BT subprogram, for instance, integrated building controls. Secondly, this objective is measured by the number of subprograms that rely upon building simulation tools that in turn actually use EnergyPlus. In both cases, the objective is considered met when 90% of the subprograms can use (by 2010) and are using (by 2010) EnergyPlus. By using a common tool and set of analysis benchmarks, BT research and standards development will be more effective.

[89] Tests in red have been codified in standards.

The second objective is to work with designers of high volume, visibility, large buildings to demonstrate the value of building simulation. First, this effort will focus on the leading firms which now use DOE-2 for building energy simulation to move them towards EnergyPlus through training workshops (3 each year for three years with continued support). This objective will be measured by how many of these firms successfully transition to EnergyPlus. In this case, the objective is considered met if two-thirds of these firms are using EnergyPlus regularly by 2008. Secondly, continuous testing and validation (using industry standards) as new capabilities are added will demonstrate that EnergyPlus can accurately simulate actual building performance and energy savings.

Each of the performance goals has a measurable path forward including how well EnergyPlus can deal with state-of-the-art technologies for net-zero and low energy Buildings and how many other BT subprograms have transitioned from other tools to EnergyPlus. Also see Table 3-49.

3.7.7 Analysis Tools Market Challenges and Barriers

Table 3-51 Analysis Tools Market Challenges and Barriers

Barrier	Title	Description	Target
A	Value of Using Simulation Not Realized	The building industry does not realize the bottom-line value of simulation analysis, and has not adopted it as part of regular practice. And an analysis tool, regardless of functionality, is worthless if no one uses it to design and retrofit actual buildings. Demonstrating and deploying the right simulation tools to key design firms therefore is a critical activity. These tools must also be shown to be accurate in their simulation of actual building operation. Building performance depends on interactions of many elements including climate, solar availability, envelope heat transfer, internal heat gains, lighting power, HVAC equipment, controls, thermal comfort, and energy cost—and these interactions are complex.	1,2,3,5
B	Lack of Interoperability Including Data Exchange Between EnergyPlus and Building Design Tools	Architectural and engineering design offices will not react well to a flood of new tools, each of which describes the building and its parts in a unique way. It would be a massive task to learn to use all of these tools and to transfer critical input and output information among the tools. A superior approach is to organize all tools around a shared, open building data model that allows each tool to transfer information seamlessly to others. This vision of “interoperability” has been discussed for many	4

Barrier	Title	Description	Target
		years but is just now reaching commercial viability worldwide under the direction of the International Alliance for Interoperability (IAI). On today's design projects, most designers routinely use CAD and cost-estimating tools. But they often don't use energy simulation tools, in part because of the time and cost of data input and output, all constrained by limited design fees. The interoperability paradigm will make it possible for energy simulators to quickly begin energy analysis using building design and geometry data imported directly from CAD tools.	
C	Ease of Use	EnergyPlus does not have an easy-to-use interface. Interface development is expensive and time consuming. One interface typically cannot serve all user needs (for instance DOE-2 has over 20 different interfaces ranging from full-feature to custom interfaces targeted at particular building components or systems. The private sector is already developing interfaces for EnergyPlus but the pace is slow and an impediment to full adoption and use in the market.	6

3.7.8 Analysis Tools Technical (Non-Market) Challenges/Barriers

Much of the underlying technical research required to establish model of technologies, systems, and controls for new simulation capabilities is performed elsewhere—either by other BT subprograms or outside research organizations, universities, and sponsoring organizations. The technical challenges for the Analysis Tools focus on balance accuracy of energy estimation techniques with usability and speed of calculation.

3.7.9 Analysis Tools Strategies for Overcoming Barriers/Challenges

The strategies for overcoming the barriers and challenges identified above are shown in Table 3-52. Much of the development activities for Analysis Tools will focus on demonstrating the value of building simulation. By working with interface developers, market leaders, and other key groups, Analysis Tools will work to overcome the interoperability and easy of use barriers.

Table 3-52 Analysis Tools Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Value of Using Simulation Not Realized	Extend the capabilities of energy analysis tools. Validate energy analysis tools.
B	Lack of Interoperability	Deploy analysis tools.
C	Ease of Use	Deploy analysis tools.

3.7.10 Analysis Tools Tasks

Table 3-53 lists the planned task for the Analysis Tools subprogram including anticipated duration and barriers addressed by each task.

Table 3-53 Analysis Tools Tasks

Task	Title	Duration	Barriers
1	Complete Incorporation of Key Features from DOE-2 and BLAST into EnergyPlus	4 quarters	A. Value of Using Simulation Not Realized, B. Lack of Interoperability
2	Incorporate New Modules to Simulate Current Technologies, Systems and Controls into EnergyPlus	20 quarters	A. Value of Using Simulation Not Realized, B. Lack of Interoperability
3	Develop Versions of EnergyPlus to Support Development and Evaluation of Low- and Zero-Energy Buildings	24 quarters	A. Value of Using Simulation Not Realized, B. Lack of Interoperability
4	Validate and test EnergyPlus calculations and performance	24 quarters	A. Value of Using Simulation Not Realized, B. Lack of Interoperability
5	Extend IEA and ANSI/ASHRAE Standard 140 methods of test to cover full matrix of validation methods for building simulation tools	24 quarters	A. Value of Using Simulation Not Realized, B. Lack of Interoperability
6	Work with leading-edge A&E firms to encourage their use of EnergyPlus	12 quarters	C. Ease of Use
7	Work with key HVAC manufacturers to encourage their adoption of EnergyPlus	12 quarters	A. Value of Using Simulation Not Realized, C. Ease of Use
8	Work with BT subprograms to transition to EnergyPlus	24 quarters	A. Value of Using Simulation Not Realized
9	Work with the International Alliance for Interoperability to ensure that building energy is integral to the interoperability standards.	12 quarters	B. Lack of Interoperability
10	Provide technical assistance to user interface developers with operational issues of EnergyPlus	18 quarters	C. Ease of Use
11	Support tools research needs of DOE R&D, track user, research,	24 quarters	C. Ease of Use

Task	Title	Duration	Barriers
	and standards development group needs, technical support		

3.7.11 Analysis Tools Milestones and Decision Points

Table 3-53 lists the key tasks BT will focus on in the Analysis Tools activity over the next six years.[90] The following milestones cover the Analysis Tools activities in FY 2005 and beyond. See the Gantt chart for a visual display of the tools activities, milestones and decision points.

Adopting EnergyPlus as Simulation Tool for BT Research and Standards Subprograms. Prepare decision memorandum for BT management regarding costs, benefits, and transition plan development. Scheduled Completion: June 2005.

Complete Incorporation of Key Features from DOE-2 and BLAST into EnergyPlus. Many current DOE-2 and BLAST users will not move to EnergyPlus if it lacks features they rely on in DOE-2 and BLAST. Bring capabilities of EnergyPlus up to current practice as represented by the combined capabilities of its predecessor programs, DOE-2 and BLAST. A limited number of capabilities remain to be added from these programs, including some that are of interest only to advanced users (which is why they weren't added to the initial releases of EnergyPlus), but which will support the High Performance Buildings initiative over time. Scheduled Completion: September 2006.

Incorporate Current Technologies, Systems and Controls into EnergyPlus. Energy standards, such as ASHRAE 90.1, ASHRAE 90.2 and California Title 24, were developed with whole-building simulation tools and future improvements to these standards cannot be developed without analysis tools. New and currently available technologies cannot be considered in a standard unless the tool used to produce the standard can model that technology. Add currently available energy-efficiency technologies that will allow EnergyPlus to be used for development of future standards and compliance with current energy standards. Incorporate Title 24 2005 ACM required capabilities, Scheduled Completion: September 2005. Adoption by CEC of EnergyPlus for development of 2008 commercial building standard, Go/No-Go expected: June 2005. Certification of EnergyPlus for Title 24 2008 ACM, Scheduled Completion: FY 2008.

Develop Versions of EnergyPlus to Support Development and Evaluation of Low- and Zero-Energy Buildings. Based on prioritization completed in FY 2004, develop increasingly more ZEB-simulation capable versions of EnergyPlus. The prioritization will be reviewed and updated on an annual basis as new technologies reach the market, in

[90] The Analysis Tools Multiyear Plan (November 2003) provided an initial list of capabilities and features which are needed to successfully model ZEB. In FY 2004 we completed an initial identification and prioritization of future ZEB features. In January 2005 the Residential Building Integration team held a workshop with the Building America teams on issues and needs for simulation tools. These needs have been added to the prioritized list of features for future releases.

consultation with leading design firms, and based on research progress in energy efficiency, renewable energy and energy supply technologies.
EnergyPlus for 40% ZEB. Add prioritized features which allow EnergyPlus to be used in development and evaluation of 40% ZEB including simulating complex building control strategies and predictive-model control. Scheduled Completion: FY 2007.
EnergyPlus for 60% ZEB. Add prioritized features which allow EnergyPlus to be used in development and evaluation of 60% ZEB including energy supply and control systems technologies. Scheduled Completion: FY 2009.
EnergyPlus for 80% ZEB. Complete prioritized features which allow development and evaluation of 80% ZEB including multizone airflow, further controls technologies and strategies as well as emerging energy supply technologies. Scheduled Completion: FY 2011.

Testing and Validation. Working with international and national industry groups, extend standard methods of test to cover the full matrix of validation methods for building simulation tools. Continue testing and validation of new features as they are added to EnergyPlus. Testing for each EnergyPlus Release, FY 2004-FY 2011. Complete IEA SHC Task 34, FY 2007. Addenda and periodic updates to ANSI/ASHRAE Standard 140 in FY 2004, FY 2007, and FY 2010.

Push Analysis Tools into the Marketplace. Work with and train two to four leading-edge engineering/architecture design firms to employ EnergyPlus as part of their everyday design practice. Work with major HVAC manufacturers to adopt EnergyPlus as the calculation engine for their programs. Identify and support the analysis tools required for BT R&D and standards development efforts. Support efforts of national and international industry organizations that promote the use of Analysis Tools through training and conferences. Working through international interoperability standards, enable seamless and robust multi-directional data flow/exchange from CAD to EnergyPlus to cost estimating to facilities management and building operations. Support International and National simulation conferences, FY 2005-FY 2011. Identify and get agreement with firms for deploying EnergyPlus, two firms each in FY 2005 and FY 2006.

Figure 3-19 Analysis Tools Gantt Chart